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SCIENCE IN EVERYDAY LIFE

BOOK TWO

VERSTRAETEN AND WATTS

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SCIENCE IN EVERYDAY LIFE

BOOK TWO

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AND

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With a Foreword by
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FOREWORD

As a result of the advances in Science and Technology the vocational foundations of the structure of Society are changing and, therefore, it is essential for all Secondary School pupils to be familiar with certain scientific ideas which underlie progressive thought and activity at all levels.

The purpose of this series of General Science books is to provide such pupils with a broad basic knowledge of scientific facts.

Mere instruction in science will not capture what is termed the 'spirit of science'. Westaway rightly points out: "The spirit of science cannot be weighed and measured even if weighing and measuring are necessary for tracking it down. It is not enough to track it down, it must be captured. . . ." The authors have succeeded, I believe, in presenting scientific ideas in a manner which will not only instruct but interest pupils and thus help them to capture the spirit of Science.

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Secretary to the Council for the Indian School Certificate Examination (University of Cambridge Local Examinations Syndicate)

SCIENCE IN EVERYDAY LIFE
FOR SENIORS

Books I, II, III and IV

Workbooks I, II, III and IV

to accompany each text-book

Teacher's Manual including Key to Workbooks

PREFACE

THIS course in General Science is meant to provide the pupils studying in Secondary and Higher Secondary Schools with a scientific outlook; it should make them aware of the impact of science and technology on their natural surroundings and on society.

Besides taking stock of the natural phenomena occurring around them, the pupils should become acquainted with the scientific methods which enable man to acquire an intellectual grasp on these phenomena and put them to use for the benefit and comfort of human society. Only in this way can the citizen of tomorrow be properly trained for the challenge of the complex life of this technological age that is awaiting him.

This is the object of the General Science course prescribed as a Core subject for all pupils studying in the Higher Secondary Schools.

The present course is based on, and follows closely, the syllabus of General Science as given in the 'Draft Syllabus for Higher Secondary Schools' issued by the All-India Council of Secondary Education, Government of India, New Delhi.

The actual break-up and the details of the course are exactly in accordance with the Syllabus in General Science adopted by the Council for the Indian School Certificate Examination and the West Bengal Board of Secondary Education for the schools under their control.

SCIENCE IN EVERYDAY LIFE is divided into five parts so as to meet the requirements of pupils in schools under the control of the West Bengal Board of Secondary Education studying General Science as a core subject from Class VI to Class X. Furthermore, the series is comprised of four books to meet the requirements of pupils in schools under the control of the Council for the Indian School Certificate Examination studying General Science as a core subject from Class(Standard)VII to Class (Standard)X.

The attention of teachers is specially drawn to the item Chapter Activities at the end of every chapter. These should be taken up along with the matter treated in the body of the chapter, as they describe simple experiments illustrating the explanations given in the chapter. Above all, these activities will make the pupils take an active and personal part in exploring their surroundings, and acquiring an orderly understanding of the day to day life of the world and the community in which they live.

A. Verstraeten
N. A. Watts

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CHAPTER I

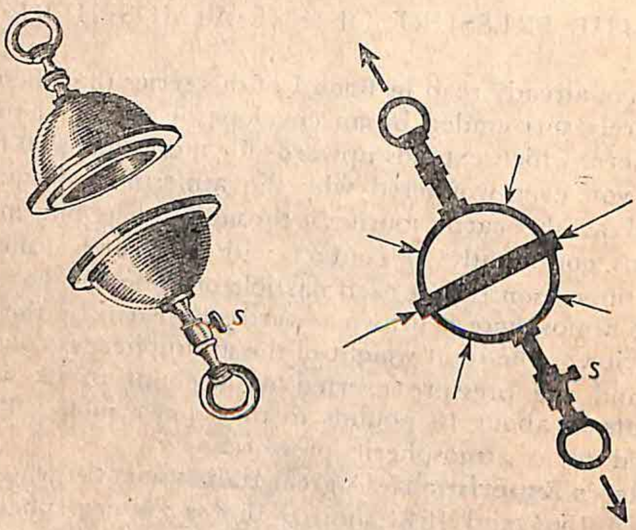
THE PRESSURE OF THE ATMOSPHERE

WE have already read in Book I of this series that the earth is entirely surrounded by an envelope of air called the atmosphere, which extends upwards for more than 200 miles. Have you ever wondered why the atmosphere is not left behind as the earth journeys through space but instead remains continually in contact with the earth's surface? Well, the reason is that each particle of the gases that make up the atmosphere is drawn towards the earth by the force of gravity. The total weight of the atmosphere is considerable and the pressure exerted on account of its weight amounts to about 15 pounds to the square inch. This is referred to as atmospheric pressure.

Galileo's Experiment. A great Italian scientist who lived between 1564 and 1642 showed that a copper sphere increased in weight when air was pumped into it, thus proving that air has weight. A modification of his experiment can be easily repeated in the school laboratory and the directions for it are given under the Chapter Activities that follow this chapter.

Otto von Guericke's Experiment. In the year 1654, a German scientist Otto von Guericke performed a spectacular experiment in the town of Magdeburg in Germany to show the existence of atmospheric pressure.

Guericke obtained two metal hemispheres of about 15 inches in diameter, whose circular rims fitted well together. Fitting the two hemispheres together so that they made a hollow ball he made the joint air-tight by means of a greased leather washer and extracted the air through a stopcock from inside the ball by means of an air pump which he invented. Next, he attached a team of horses to each hemisphere and arranged for the two teams to pull against each other so as to pull the hemispheres apart. It required eight



Magdeburg hemispheres.
The thin arrows show the direction of air pressure. The thick arrows show the direction of pull.
s, stopcock.

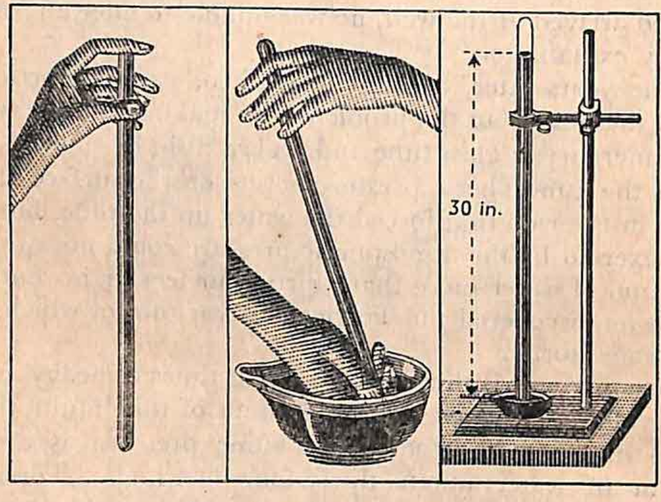
horses in each team before separation of the hemispheres could be effected. By doing this experiment Guericke clearly demonstrated the magnitude of the force which arises from the action of air pressure and also showed that air presses in all directions.

Torricelli's Experiment. In the time of Galileo, the Duke of Tuscany sunk a well on his estate to a depth of forty feet. He fitted a lift pump to the well in order to draw up the water. The Duke found, however, that the water in the well could not be raised more than thirty-four feet. Although the pump piston moved to the top of the tube, the water could not rise any further and there was an empty space or vacuum between the top surface of the column of water and the lower surface of the piston. It was generally believed at the time that nature abhorred a vacuum and would not allow it to exist. The Duke sent for Galileo to solve the problem. When Galileo arrived at the well, he was unable to offer any satisfactory explanation.

Some years later, a pupil of Galileo, named Torricelli, found the answer to the problem. By making a model well, using mercury, a glass tube and a glass dish, he showed that it was the atmospheric pressure acting on the surface of the water in the well that forced the water up the tube, but the force exerted by the atmospheric pressure could not support a column of water more than thirty-four feet high. Further to this he discovered the Torricellian vacuum of which you will read shortly.

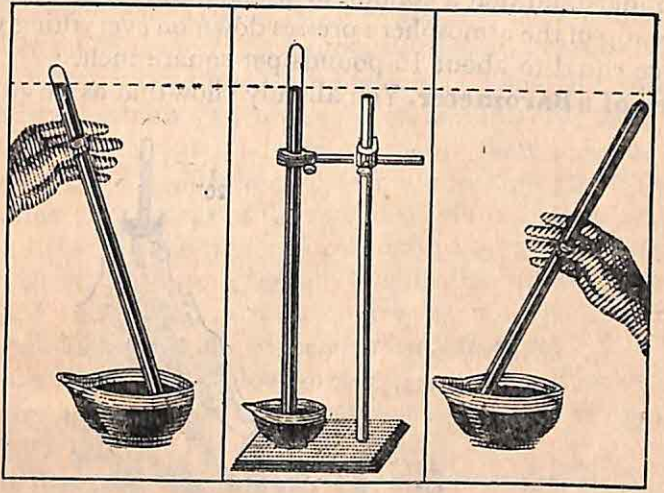
Since mercury is thirteen and a half times as heavy as the same volume of water, a short column of this liquid thirty inches high would produce the same pressure as a long column of water about thirty-four feet high. Torricelli knowing this chose mercury, as it would enable him to make his model in a more compact form. By using vessels made of glass he could observe what was happening. The model he made, called the Simple Barometer, can easily be constructed in the laboratory.

The Simple Barometer. Take a clean dry glass tube about 34 inches long and closed at one end. Fill the tube with mercury. Remove any air bubbles that may be sticking to the sides of the tube by tapping the tube gently. Place a finger over the open end and, inverting the tube, place this end in a small dish of mercury. When the end of the tube is under the surface of the mercury in the dish remove your finger and notice what happens. You might expect the heavy liquid to fall out of the tube with a flop. Instead it drops a few inches at the top of the tube leaving a space. Since you commenced the experiment with a tube full of mercury and no air was seen to enter the tube, the space above the mercury in the tube cannot be air. What is it then? It is a vacuum—a space



How to make a barometer.

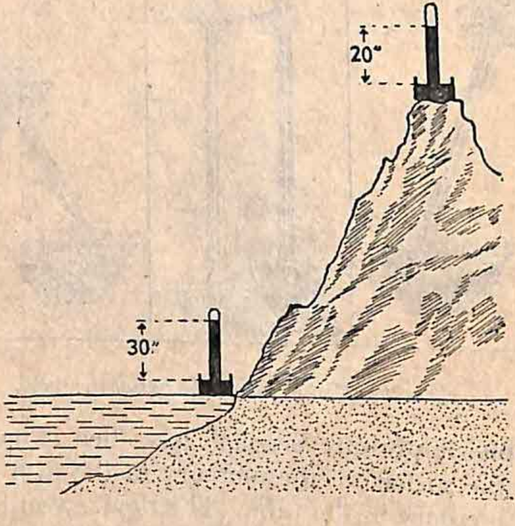
containing nothing. You can easily see that there is nothing in this space, for if you tilt the tube over to one side the mercury fills the tube right to the top. As you hold the tube vertically, however, the space appears again. Now, the vacuum at the top of the mercury in the tube, being nothing, can neither push nor pull the column of mercury, whereas the mercury in the dish has the air pressing on it. The weight of the atmosphere pressing on the surface of the mercury in the dish prevents the mercury from falling any further in the tube. At whatever angle the tube is tilted, the vertical height from the surface of mercury in the dish to the top of the mercury column remains the same until the mercury completely fills the tube. The vacuum at the top of the mercury column is called the Torricellian vacuum after the man who discovered it. If for any reason the atmospheric pressure becomes greater, then it presses harder on the surface of the mercury in the dish and up goes the mercury in the tube; if the atmospheric pressure becomes less, then it presses more lightly on the surface of the mercury in the dish and down comes the mercury in the tube. The device you have made is called the Simple Mercury Barometer and can be used to measure the pressure of the atmosphere.



To show the effect of tilting the barometer tube.

Suppose the tube has a cross-sectional area of one square inch. The distance between the top of the mercury column and the surface of mercury in the dish will be about 30 inches at sea level. Then the volume of mercury in the tube will be 30 cubic inches. Now, since the weight of one cubic inch of mercury is about half a pound, the weight of 30 cubic inches of mercury is about 15 pounds. The pressure of the mercury column on an area of one square inch is therefore about 15 pounds. Hence we know that the pressure of the atmosphere must be about 15 pounds to the square inch as well, for it balances a column of mercury of that weight. From this we can understand that a column of air extending from sea level to the top of the atmosphere presses down on everything with a force equal to about 15 pounds per square inch.

Uses of a Barometer. You already know that as we go higher the pressure of the atmosphere decreases. If a barometer is taken to the top of a tall mountain a drop in the level of mercury will be observed. For every thousand feet we ascend, the column of mercury falls approximately one inch. By measuring the height of the mercury column we are able to get some idea of the height of the mountain. By studying



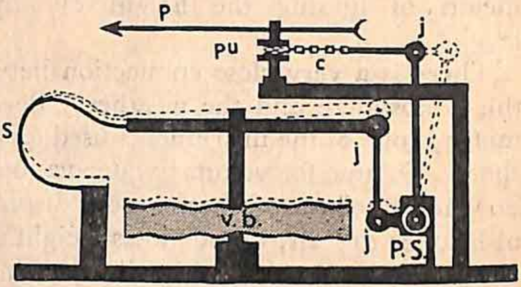
How high is this mountain ?

the readings of the barometer we therefore have a ready means of finding the height of any place above sea level.

There is a very close connection between the pressure of the atmosphere and the weather. Because of this a barometer is one of the instruments used for forecasting the weather. Volume for volume, water vapour is lighter than air. So when a volume of water vapour displaces an equal volume of heavier dry air, the air loses weight. Thus, air which is dry is heavier than air which is moist and the pressure of the atmosphere is greater on fine dry days than it is on dull rainy days. This increase or decrease in atmospheric pressure affects the height of the mercury column. A sudden fall in the height of the mercury column means a sudden fall in atmospheric pressure, generally due to the increase of moisture. A sudden fall in the mercury column usually heralds an approaching storm. Since air moves from regions of high pressure to regions of low pressure, a study of barometric readings gives valuable information on the directions of winds.

The Aneroid Barometer. The mercury barometer is not very portable being cumbersome and fragile, so it is often replaced by another kind called the aneroid barometer, which literally means 'a barometer containing no liquid'. The prominent feature of this instrument is a flat box made of very thin, elastic metal from which most of the air has been withdrawn. Because of the partial vacuum inside the box the surface moves in and out, corresponding to the changes in air pressure. The box is corrugated so as to respond more readily to the slightest alteration of air pressure on its surface especially at its centre.

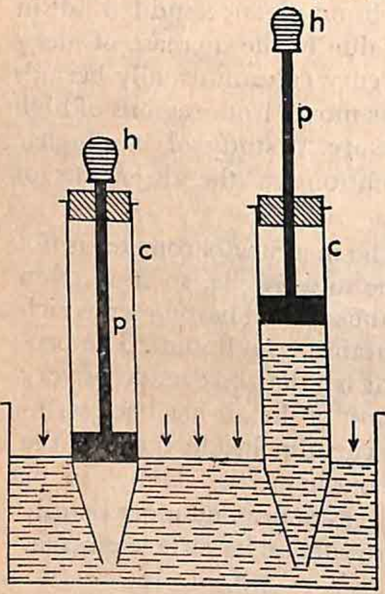
Changes in air pressure affect the shape of the box very slightly. A complicated system of levers magnify the movements produced on the surface of the box and cause a pointer to rotate round a dial. The figures on the dial have been graduated to read correctly by direct comparison with a mercury barometer.



The aneroid barometer.
c, chain; j, loose joint; p, pointer; pu., pulley; p.s., pivot shaft; s, spring; v. b., vacuum box.

Aneroid barometers are used by airmen as altimeters in which case they are graduated in such a way that they indicate altitude instead of pressure.

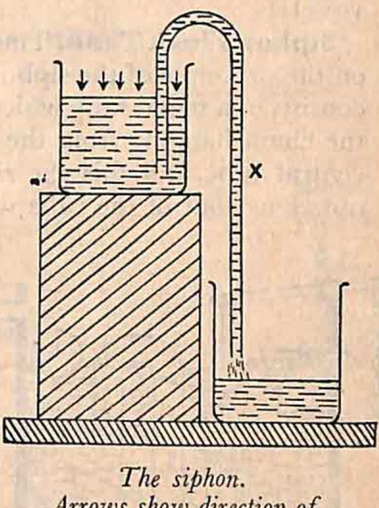
The Syringe. We shall now study a few familiar mechanical devices that are dependent on atmospheric pressure. The syringe is one of these. It consists of an airtight piston which fits into a cylindrical tube. The lower end of the tube tapers to a nozzle. When the nozzle is placed under water and the piston pulled up, the pressure in the space between the lower end of the piston and the nozzle becomes less than that of the atmosphere,



The syringe.
Arrows show direction of atmospheric pressure.
c, cylinder; h, handle; p, piston.

since the small amount of air left in this space has to fill the enlarged space created by the upward movement of the piston. Atmospheric pressure now forces water into this space and the tube becomes almost filled. After the syringe has been removed from the water the atmospheric pressure acting on the surface of the water at the lowest end of the tube keeps the water in the syringe. The water in the tube can, however, be pushed out if a pressure greater than that of the atmosphere is brought to bear on it.

Pipettes, fountain-pen fillers and self-filling fountain-pens are further examples of devices that work on the same principle as that of the syringe.



The siphon.
Arrows show direction of atmospheric pressure.

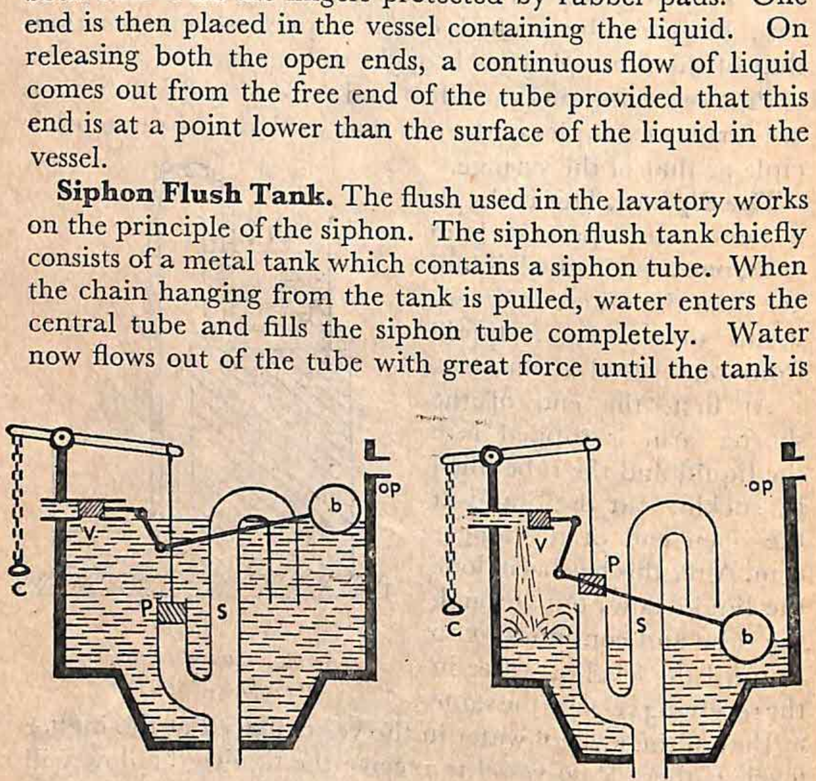
The Siphon. This is simply a bent tube open at both ends, one arm of which is longer than the other. It is very useful to transfer a liquid from one vessel to another.

At first, the end of the shorter arm is dipped into the liquid and the tube filled by sucking out the liquid at the open end of the longer arm. After this has been done the liquid flows out through the tube and continues to do so until the level of water in the receiving vessel is the same as that of the level of water in the vessel placed at the higher level. If there is no vessel to receive the liquid, the flow will continue until the level of the liquid has dropped to the end of the short arm.

The explanation for this is that the air pressure at both ends of the tube is the same. At the point X the pressure is less than at the end which is dipped into the liquid and therefore the water flows towards the point X and then out of the tube.

If the liquid to be transferred is harmful to the body, the air from the tube must not be removed by sucking. In such a case the tube may be filled with the liquid and closed at both ends with the fingers protected by rubber pads. One end is then placed in the vessel containing the liquid. On releasing both the open ends, a continuous flow of liquid comes out from the free end of the tube provided that this end is at a point lower than the surface of the liquid in the vessel.

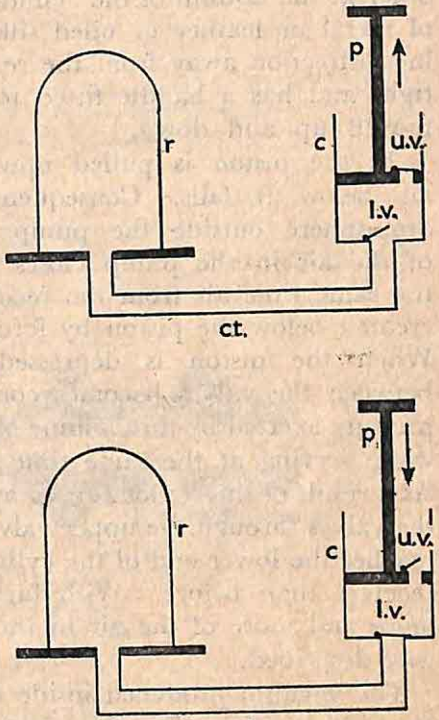
Siphon Flush Tank. The flush used in the lavatory works on the principle of the siphon. The siphon flush tank chiefly consists of a metal tank which contains a siphon tube. When the chain hanging from the tank is pulled, water enters the central tube and fills the siphon tube completely. Water now flows out of the tube with great force until the tank is



The siphon flush tank.
Left: before the chain is pulled. Right: after the chain has been pulled. b, hollow copper ball; c, chain; o.p., overflow pipe; p, plug; s, siphon tube; v, valve.

almost empty. As the level of water in the tank falls, the large hollow copper ball floating on the surface of the water is lowered. A metal shaft connected to the ball at one end and attached to a piston at the other now slides along a part of the inlet pipe allowing water to flow into the tank from a hole in the inlet tube. As the tank fills with water, the ball is carried upwards with the rise of the level of water. This causes the piston to close the hole in the inlet tube thus stopping the flow of water into the tank. By the time this has happened the water has risen to a point just below the level of the siphon tube. An overflow pipe is fitted to the tank to prevent the tank becoming flooded in the event of the ball valve failing to close.

The Air Pump. This pump, also known as the exhaust pump, is employed for withdrawing as much air as possible from a container. The vessel from which air is to be exhausted, called



The air pump.
Above : up-stroke.
Below : down-stroke.
The arrows show the direction in which the piston moves.
c, cylinder ; c.t., connecting tube ; l.v., lower valve ; p, piston ; r, receiver ; u.v., upper valve.

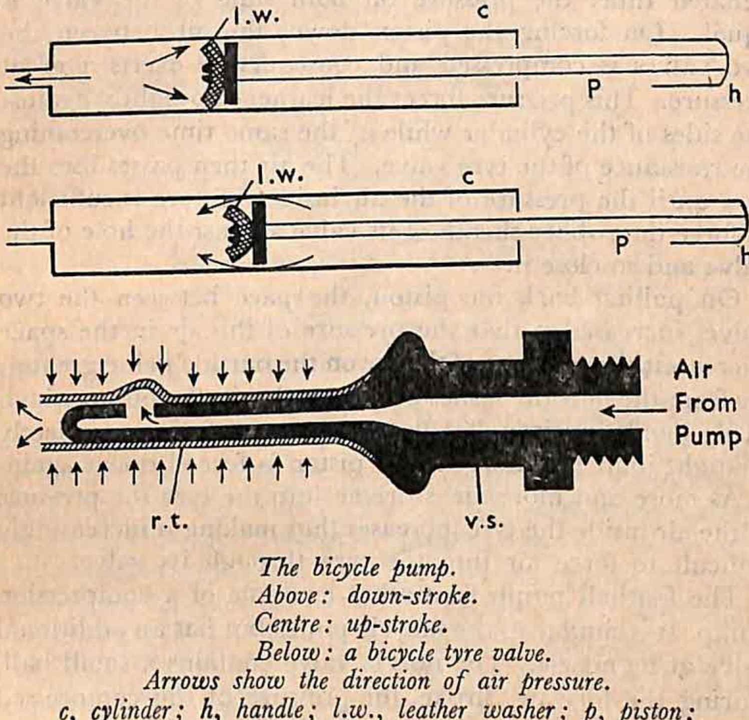
the receiver, is connected by means of a tube bent twice at right angles to a cylinder. Contrivances which allow air or a liquid to pass in one direction only, called valves, are situated in the cylinder, one in the piston and the other at the bottom of the cylinder. Both valves are made of metal or leather or oiled silk and open upwards, i.e. in a direction away from the receiver. The piston is air-tight and has a handle fitted to it which allows it to be moved up and down.

As the piston is pulled upwards the pressure of the air below it falls. Consequently, the pressure of the atmosphere outside the pump being greater than that of the air in the pump closes the upper valve while at the same time air from the receiver rushes into the space created below the piston by forcing open the lower valve. When the piston is depressed, the air in the space between the valves becomes compressed and the resulting pressure exerted by this volume of air closes the lower valve while serving at the same time to open the upper valve. As a result of this action, air escapes from the space between the valves through the upper valve. Thus, when the piston reaches the lower end of the cylinder there is less air in the receiver than before. With further strokes of the piston more and more of the air in the receiver is moved in the way described.

The vacuum produced inside the receiver is never complete since, even after the piston has been worked many times, the pressure of the air remaining in the receiver is unable to force open the valves.

The air pump was invented by Otto von Guericke and used by him to produce a vacuum inside the hemispheres used for his famous experiment on air pressure at Magdeburg.

Compression Pump. The bicycle pump is an example of a compression pump. It consists of a cylinder made of vulcanite or metal provided with an air-tight piston. The piston is moved in and out by a handle. A cup-shaped piece of leather fitted to the piston acts as a valve and has its concave side facing the exit tube.



The bicycle pump.
Above: down-stroke.
Centre: up-stroke.
Below: a bicycle tyre valve.
Arrows show the direction of air pressure.
c, cylinder; h, handle; l.w., leather washer; p, piston; r.t., rubber tubing; v.s., valve stem.

The compression pump is used for compressing air into a receiver. It is for this reason that its valve opens towards the receiver.

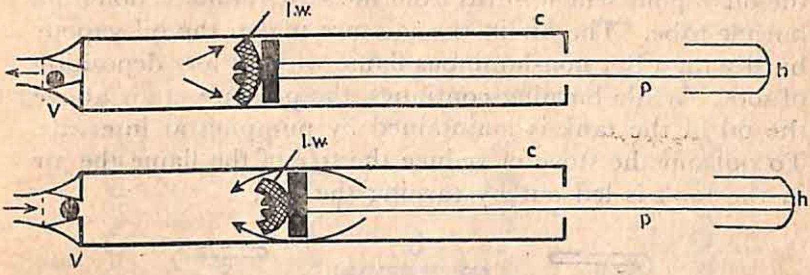
The air-tube of a bicycle tyre also has a valve connected to it. This valve is simply a narrow metal tube with a closed end and a small hole on its side. A small sheath of thin rubber tubing is fitted tightly over this tube. The valve allows air to pass in one direction only, i.e. towards the receiver.

When the bicycle pump is connected to the valve of the deflated tube, the pressure on both sides of the valve is equal. On forcing the piston down, the air between the two valves is compressed and consequently exerts a great pressure. This pressure forces the leather cup tightly against the sides of the cylinder while at the same time overcoming the resistance of the tyre valve. The air then passes into the tyre until the pressure of the air inside the tyre is sufficient to force the rubber sheath of its valve against the hole of the valve and so close it.

On pulling back the piston, the space between the two valves increases so that the pressure of the air in the space decreases; the pressure of the air on the outside being greater, air from the outside pushes past the valve in the pump which easily bends inwards, but flattens out and forms a perfectly air-tight joint the moment the piston is forced down again.

As more and more air is driven into the tyre the pressure of the air inside the tyre increases thus making it increasingly difficult to force air into the tyre through its valve.

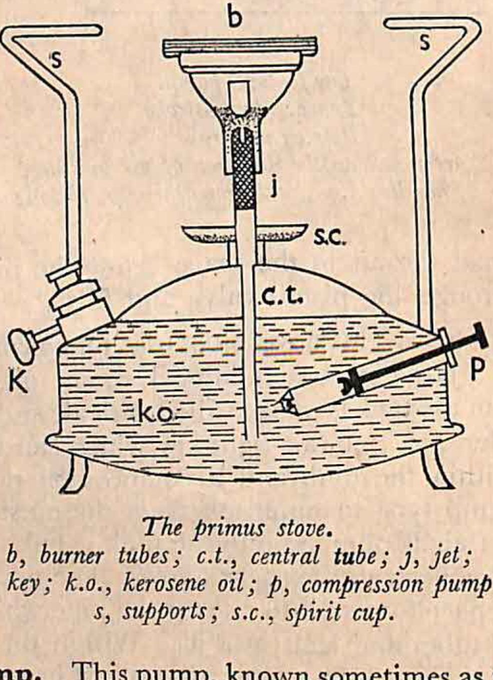
The football pump is another example of a compression pump. It is similar to the bicycle pump but has an additional valve at its nozzle. The nozzle valve contains a small ball. During the forward stroke, the pressure of the compressed air within the cylinder becomes higher than the pressure of air within the receiver and the ball in the nozzle valve moves to one side to allow air to pass from the pump to the receiver. During the backward stroke the volume of enclosed air between the valves expands and forces the ball in the nozzle valve to fit air-tight in the exit hole and thus prevent any air from leaking out. Air from the outside having a greater



The football pump.
Above: down-stroke.
Below: up-stroke.
Arrows show the direction of air pressure.
c, cylinder; h, handle; l.w., leather washer; p, piston; v, ball valve.

pressure than the air in the space below the piston, forces its way through the piston valve and fills the space.

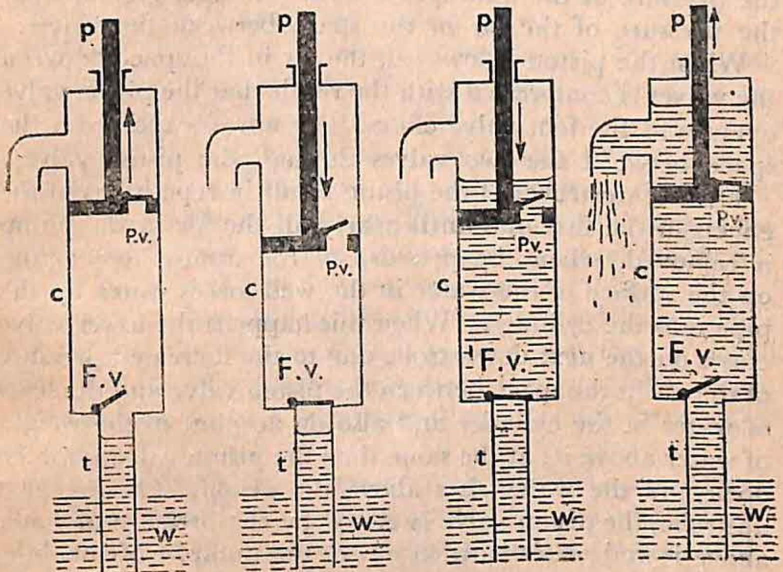
Primus Stove. This stove, often used for cooking purposes, consists of a large tank containing kerosene oil. Above the level of oil in the tank is a space filled with air and oil vapour. Fitted to the tank is an air-tight key which can keep air entrapped within the tank and a compression pump of the football pump type to pump air from the outside into the tank. When air is pumped into the tank it bubbles through the oil and collects in the space above. The pressure of the air in this space forces oil to rise up the pipe which leads to the burner tubes and ends in a jet. Within the top of the pipe is a wire gauze. The wire gauze is first heated by burning some methylated spirit in the metal cup around it. Before the flame goes out, the pump is worked so as to force oil up the tube. As the oil reaches the wire gauze it is vaporised and the oil vapour together with air from the tank issues from the jet and circulates within the burner tubes at the funnel. The heat of the burner tubes is sufficient to ignite the oil vapour which burns from the series of holes along the burner tube. The air in the mixture makes the oil vapour burn with a hot non-luminous flame without any deposition of soot. While burning continues, the pressure of air above the oil in the tank is maintained by pumping at intervals. To put out the stove or reduce the size of the flame the air in the tank is led out by turning the key.



The primus stove.
b, burner tubes; c.t., central tube; j, jet;
k, key; k.o., kerosene oil; p, compression pump;
s, supports; s.c., spirit cup.

Lift Pump. This pump, known sometimes as the suction or common pump, is used for drawing water from a well. It is the oldest type of pump and has been used for centuries—even before the time of Galileo.

The pump consists of a cylinder which is connected by a pipe to the well from which water is to be raised. Inside the cylinder is a piston which can be raised or lowered by working the pump handle. There is a valve at the point where the pipe joins the cylinder, called the foot valve. Another valve, called the piston valve, is fitted in the piston. Both valves open upwards, i.e. away from the water in the well.



How a lift pump works.
Arrows show the direction in which the piston moves.
c, cylinder; f.v., foot valve; p, piston; p.v., piston valve; t, tube; w, water in well.

When the piston is raised from a position at the lower end of the cylinder, the air in the space between the valves now occupies a much larger volume and hence its pressure decreases, i.e. its pressure becomes lower than the pressure of air below the foot valve, and so the foot valve is lifted and air flows into the cylinder. The flow of air from the pipe causes the pressure of the remaining air in the pipe to be lower than that of the atmosphere. Consequently, water is pushed up in the pipe to a certain distance by the atmospheric pressure acting on the surface of the water in the well. During this upstroke, the piston valve remains closed due to the pressure of the atmosphere above it being greater than the pressure of the air in the space between the valves.

When the piston is lowered, the air in the space between the valves is compressed with the result that the piston valve opens and the foot valve closes. Air now escapes from the space between the two valves through the piston valve.

Further upstrokes of the piston result in repetitions of the effects of the first one until nearly all the air in the pump is removed, when the pressure of the atmosphere acting on the surface of the water in the well forces water up the pipe into the cylinder. When this happens the lower valve closes on the next downstroke due to the increased pressure of the air in the space between the piston valve and the level of water in the cylinder and also on account of the weight of water above it; at the same time the piston valve is forced open and the water rises above the piston. On the next upstroke, the piston valve is closed by the pressure of water above it and water is lifted out of the pump. Meanwhile, the reduction of pressure below the piston has caused the pressure of the atmosphere acting on the surface of the water in the well to force more water up the pipe and to open the foot valve so as to allow more water to enter the cylinder in preparation for the next downstroke. The flow of water from the spout is intermittent, i.e. water only gushes from the spout during an upstroke.

Theoretically, the atmospheric pressure acting on the surface of the water in the well is sufficient to hold up a column of water thirty feet in height. In actual practice, however, the limit is usually about twenty-five feet. This is due to imperfections of the valves and leakages which occur between the rim of the piston and the inner sides of the cylinder.

Force Pump. In this pump the piston is solid. The foot valve, as in the case of the lift pump, opens upwards. The outlet pipe is fitted at a point close to the bottom of the cylinder. A valve which opens outwards is provided at the junction of the cylinder and outlet pipe.

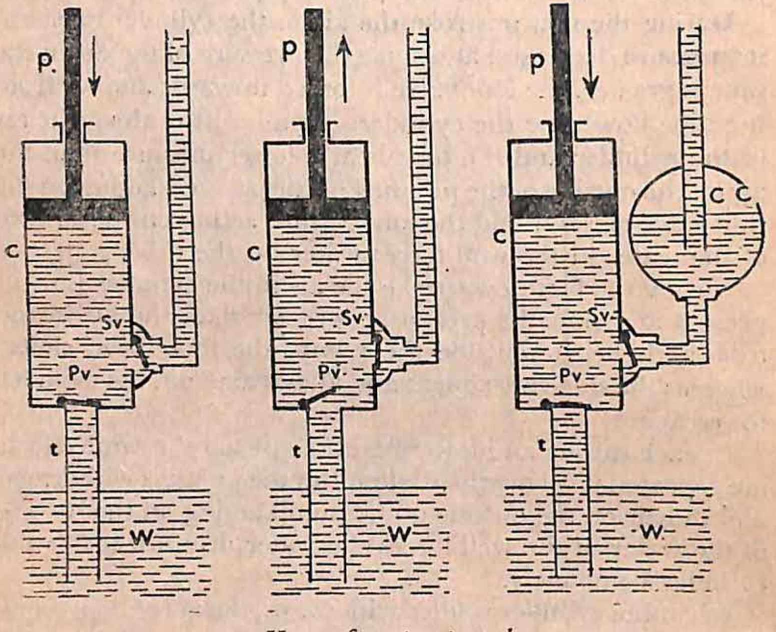
During the first upstroke the air in the cylinder expands, its pressure decreases, and since the pressure of the air in the pipe is greater, the foot valve is forced upwards and air from the pipe flows into the cylinder. As a result of this, the air in the cylinder and the pipe is at a lower pressure than the air on the outside of the pump. The air pressure acting on the side valve closes it and the air pressure acting on the surface of the water in the well forces water up the tube.

During the first downstroke the air in the cylinder is compressed and since its pressure is greater than the air in the tube and the air outside the pump, the foot valve closes, whereas the side valve opens and allows air from the cylinder to escape.

At each raising and lowering of the piston the same effects are repeated until nearly all the air in the pump is withdrawn and the air on the outside of the pump acting on the surface of the water in the well forces the water up until it fills the cylinder completely.

When the cylinder is filled with water, the act of depressing the piston increases the pressure on the water. This results in the foot valve closing while at the same time the side valve is forced open and water flows out of the side tube. The act of raising the piston now causes water to rise up the pipe into the cylinder through the foot valve which flips open. During this upstroke, however, the side valve remains closed due to the back pressure of water in the side tube.

The force pump, like the lift pump provides us with an intermittent flow of water. Its advantage over the lift pump is that it can raise water to any height depending on the strength of the machine and the force with which the piston is driven downwards. Further to this, the flow of water from the exit tube can be made continuous by having an air chamber attached to the exit tube. If this is done, then on



How a force pump works.
Arrows show the direction in which the piston moves.
c, cylinder; c.c., compressed air chamber; p.v., foot valve; p, piston; S.v., side valve; t, tube; w, water in well.

each downstroke, water accumulates in the chamber. If the piston is rapidly worked, then during successive downstrokes water collects rapidly in the chamber and compresses the air in the chamber. The air being compressed, the water is forced out of the delivery tube even during upstrokes of the piston and in this way a continuous flow of water from the delivery tube is maintained.

Boyle's Law. If we draw out the piston of a bicycle pump and then close the outlet with a finger we will observe that as the piston is forced inwards, the air in the cylinder gets compressed and it becomes increasingly difficult to move the piston further inwards. This shows that as the volume occupied by the air decreases, its pressure increases. All gases behave very much like this. An English scientist named Boyle showed in 1662 that when a gas is compressed to half its volume its pressure becomes twice as great, when compressed to one-quarter of its volume, its pressure becomes four times as great, and so on. Quantities that are related in this manner are said to be inversely proportional to each other or, in other words, as expressed by Boyle's law, the volume of a given quantity of gas at constant temperature is inversely proportional to the pressure to which it is subjected. Another way of expressing the law is that the product of the pressure and the volume of a given quantity of gas is constant, provided the temperature remains constant.

Thus,

if P=Pressure, V=Volume, and K=Constant

$$V=\frac{K}{P}$$

$$\text{or } PV=K$$

The experimental verification of Boyle's law is given under the Chapter Activities that follow this chapter.

Boiling Point and Pressure. The boiling point of a liquid depends on the pressure to which the liquid is subjected. When we say that the boiling point of water is 100°C., it is taken for granted that the water is pure and under normal atmospheric pressure, i.e. 76 cm. of mercury. If we increase

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the pressure above the surface of the liquid, the boiling point of the liquid rises, and conversely, if we decrease the pressure above the surface of the liquid, the boiling point of the liquid falls. This leads us to conclude that the boiling point of a liquid varies with the pressure to which the surface of the liquid is exposed. For example, water will boil at a temperature lower than 100°C. if the atmospheric pressure is lower than 76 cm. As you already know, the pressure of the atmosphere decreases with the rise in altitude. So on the top of a high mountain, water will not boil at 100°C. but at a temperature lower than this. Hence, at very high altitudes it becomes impossible to cook food properly in water contained in open vessels. This difficulty can be overcome by cooking food in closed vessels in which the vapour formed from the surface of the heated water is not allowed to escape, but is used instead to increase the pressure on the surface of the water and thus raise the boiling point.

Papin's Digester. The fact that the boiling point of water is raised with the increase of pressure on the surface of the water finds application in an instrument known as Papin's digester. It consists of a large metal vessel fitted with a lid which can be clamped down with screws. When the lid is screwed down and water is heated in the vessel the steam is trapped and the resulting pressure exerted by the steam on the surface of the water in the vessel steadily raises the boiling point of water and prevents actual boiling. Papin's digester, also known as a pressure cooker, is always fitted with a safety valve that releases the steam inside the vessel at a given pressure so that the water then boils at a temperature corresponding to that particular pressure.

Chapter Activities

Outdoors

1. Keep a constant watch for gadgets, toys and machines that rely on air for their working. Divide them into groups according to whether they depend on :

(*a*) Air for their support. (*b*) Moving air.
(*c*) Air pressure. (*d*) Compressed air.

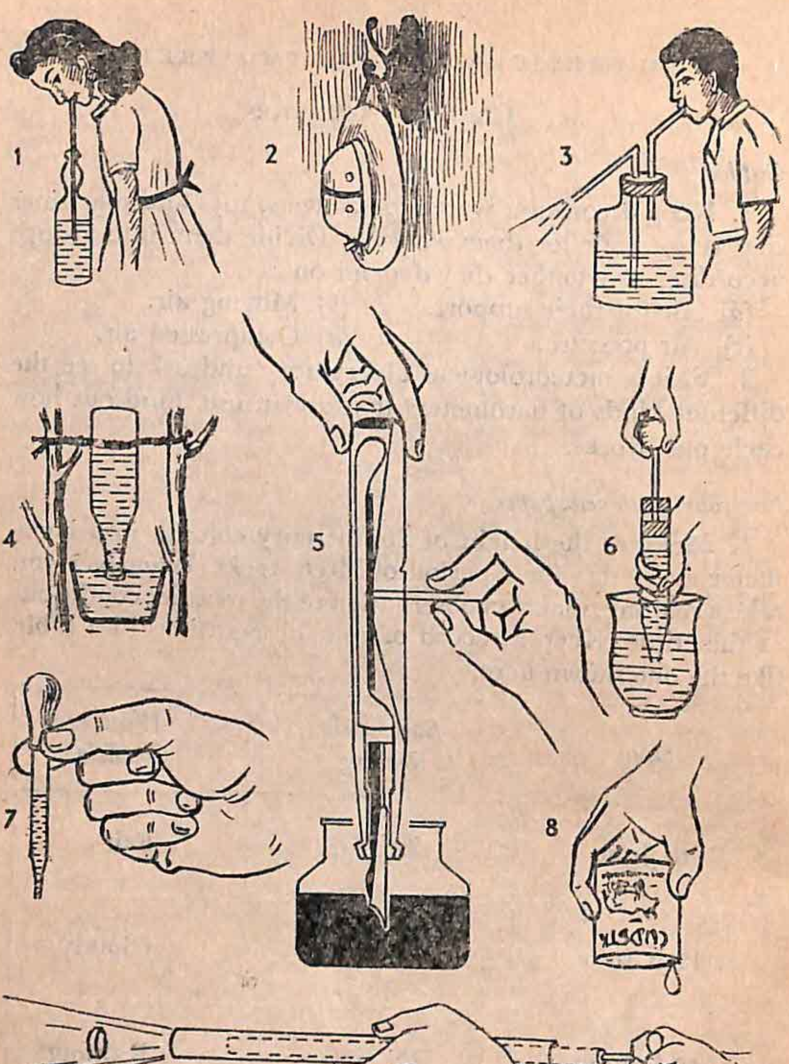
2. Visit a meteorological observatory and ask to see the different kinds of barometers that are in use. Find out how each one works.

For your wall newspaper

1. Measure the height of the mercury column in a barometer every day for a period of three weeks. Whenever you take a reading, make an observation of the weather conditions at that time. Keep a record of your observations in a table like the one shown here.

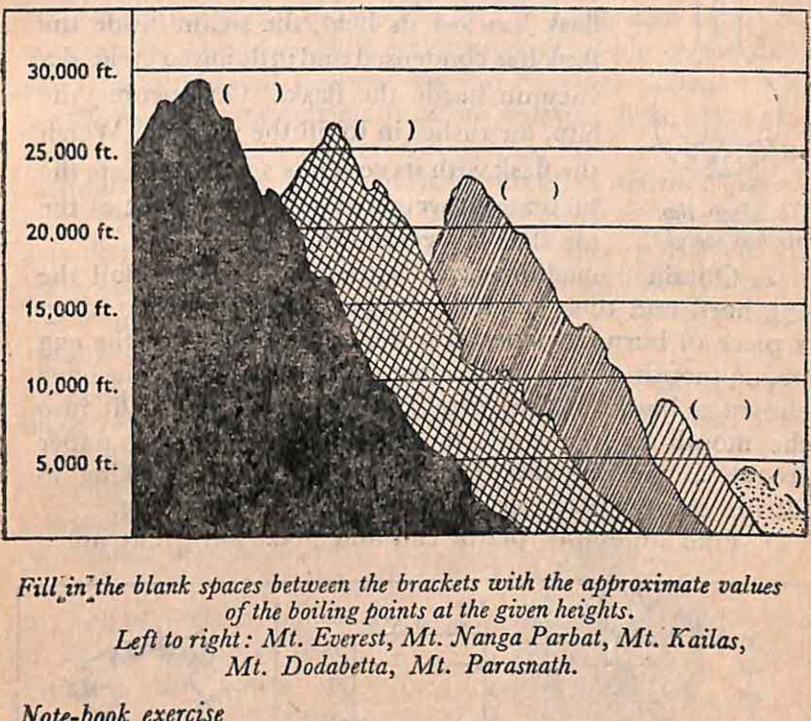
Date	*Barometric Reading*	*Weather Condition*
10th June	$29\frac{1}{2}$ in.	Fair
11th June	$29\frac{1}{4}$ in.	Cloudy
12th June	29 in.	Raining

2. The boiling point of water falls approximately 1°C. for every 960 feet increase in elevation above sea-level. Make a chart like the one shown on page 25, to illustrate how the



Draw arrows to show the direction of air pressure.
1. Enjoying a cool drink. 2. A rack without nails. 3. A wash-bottle. 4. A fountain for fowls. 5. A fountain-pen. 6. Syringe. 7. A fountain-pen filler. 8. A tin of condensed milk. 9. A pop-gun shooting potato bullets.

boiling point of water varies with the altitude. Cut up sheets of coloured paper into the shapes of mountains. Fill in the blank spaces between the brackets with the approximate values of the boiling points at the given heights.



Fill in the blank spaces between the brackets with the approximate values of the boiling points at the given heights.
Left to right: Mt. Everest, Mt. Nanga Parbat, Mt. Kailas, Mt. Dodabetta, Mt. Parasnath.

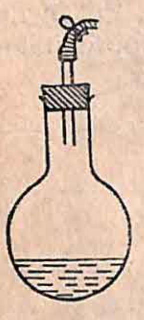
Note-book exercise

Describe how air pressure helps the things pictured on page 24 to work.

Laboratory work

1. Take a round-bottomed flask and pour some water in it. Fit the flask with a one-holed stopper through which a piece of glass tubing passes. Fix a piece of rubber tubing to

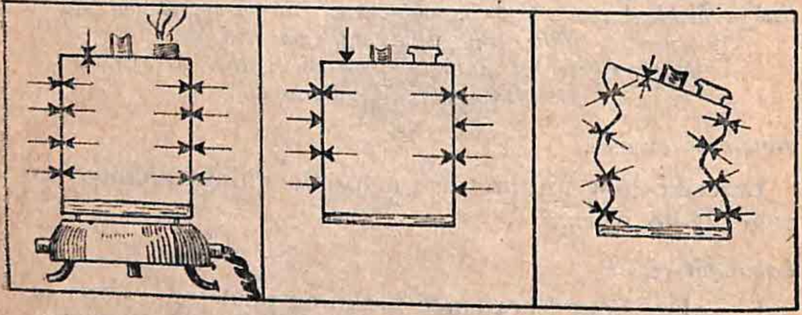
the top of the glass tube. Heat the flask until the steam has driven out all the air. Remove the flame and close the tube with a clip. Allow the flask to cool and then weigh the flask with its contents. Now release the clip. Since the flask has lost its heat, the steam inside the flask has condensed and in doing so created a vacuum inside the flask. On opening the clip, air rushes in to fill the vacuum. Weigh the flask with its contents again and note the increase in weight due to the weight of the air that has rushed in.



To show that air has weight.

2. Obtain a medium-sized bottle and an egg. Boil the egg hard and then carefully remove the shell. Next, drop a piece of burning paper into the bottle and place the egg in the mouth of the bottle after a few seconds. If you have chosen a bottle of the correct size the egg should fit into the mouth as if it were an egg-cup. The burning paper creates a vacuum and the air on the outside, seeking to fill the empty space, rushes inside driving in the egg.

3. Find an empty petrol can and make sure that not a



Air pressure versus partial vacuum.
Arrows show the direction of air pressure.

drop of petrol is left in it. Remove the stopper and pour in half a cup of water. Set the can over a stove and heat the water for several minutes. When the water in the can boils, the steam formed drives out most of the air from the inside of the can. Replace the stopper and allow the can to cool. As the steam cools it changes to water and a partial vacuum forms within. The small amount of air in the can exerts a very small pressure on the tin sides which is no match for the atmospheric pressure working from the outside. Finally, with creaks and groans the can begins to crumple, crushed as it were in the hands of an invisible giant.

4. Immerse a tumbler in a bowl of water so that it fills and then carefully invert the tumbler, raising it partly out of the water. The pressure of the air acting on the surface of the water in the bowl balances the weight of water in the tumbler.

Obtain a long tube, cork one end of it, and fill it with water. Put your thumb over the open end and invert the tube. Place the open end in a bowl of water and remove your finger. You will notice that the water column is not lessened in height. Here again it is air pressure that supports the water in the tube. The pressure of the air is so great that it can hold up a column of water nearly thirty-four feet high.

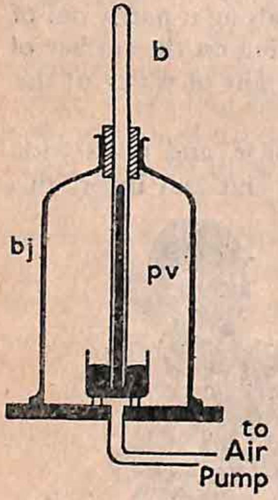
Air pressure supports these water columns.

5. You have read in the text that in con-

structing a mercury barometer, care must be taken to see that no air enters the barometer. Introduce a few air bubbles, by means of a pen filler into the vacuum of a Simple Mercury Barometer and explain the result. Again, the text lays emphasis on the fact that the mercury used in constructing a barometer must be dry. Introduce a few drops of water by means of a pen filler into the vacuum and try to explain your observations.

6. Place an inflated toy balloon under the bell jar of an air-pump. Exhaust the air from the bell jar. Explain the result.

7. That the mercury column of a barometer is actually held up by the pressure of the atmosphere on the surface of the mercury in the dish can be clearly demonstrated by varying the pressure with the help of an air pump as shown. Note what happens to the level of the mercury in the barometer as the air in the receiver is withdrawn and when air is again allowed to enter the receiver.

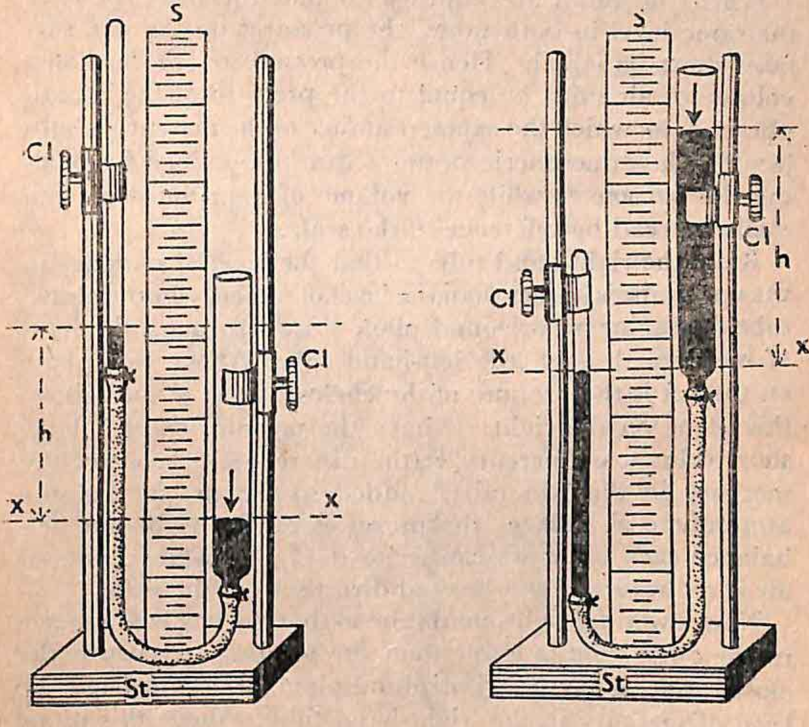


A barometer in the receiver of an air pump. b, barometer; b.j., bell jar; p.v., partial vacuum.

8. Obtain a bicycle pump, take it to pieces and study the various parts. What change in the action of the pump is brought about by reversing the washer?

9. To verify Boyle's law take the apparatus shown in the figure known as Boyle's law apparatus. This apparatus consists of two pieces of glass tubing, the one on the left about 30 cm. long and 5 mm. in diameter is sealed at the upper end, while the other tube is somewhat shorter and wider and

open at both ends. The two tubes are connected by a length of rubber tubing securely wired on to the lower ends of each tube.



Apparatus for the verification of Boyle's law.
The unbroken arrows show the direction of atmospheric pressure.
Cl., clamps; S, scale; St., stand; x-x points at which pressures are equal.

To prepare the apparatus for the experiment, first straighten out the tubes and pour in mercury until it stands at a level approximately one third the length of the tubes. Make the tubes erect and fit them to a board which includes a wooden scale. Our readings must now be concerned with the volume of the air contained in the closed tube and the pressure it exerts.

When the tubes are adjusted so that the mercury is at the same level in both tubes, the pressures on the two surfaces must be equal. Hence the pressure on the enclosed volume of air must be equal to the pressure of the atmosphere A to which the exposed surface of the mercury is subjected. The atmospheric pressure can be obtained by reading the barometer while the volume of imprisoned air can easily be read by reference to the scale.

Raise the right-hand tube so that the level of mercury in the open tube is higher than the level of mercury in the closed tube. Imagine a horizontal plane drawn through the level of mercury through the left-hand tube. Above this plane on the left is the pressure of the enclosed gas P and above this plane on the right we have the pressure exerted by a short column of mercury h (the difference in levels of the mercury in the two tubes) added to the pressure of the atmosphere A. Since the pressures on the right and left balance each other we can write $P=h+A$. The volume of air is reduced and can be read directly from the scale.

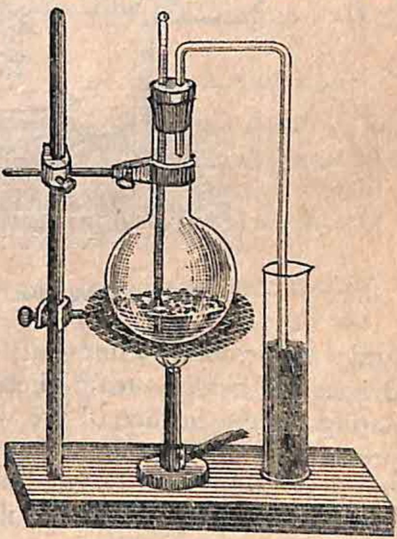
Now lower the right-hand tube so that the level of mercury in the open tube is lower than the level of mercury in the closed tube. Imagine a horizontal plane drawn through the level of mercury in the right-hand tube. Above this plane on the right we have the pressure of the atmosphere A and above the plane on the left we have the pressure exerted by a short column of mercury h (the difference in levels of the mercury in the two tubes) added to the pressure of the enclosed volume of gas P. Since the pressures on the right and left balance each other we can write $A=h+P$ or $P=A-h$. The volume of air is increased and can be read directly from the scale.

Your readings may be tabulated as follows:

Atmospheric Pressure (A) *in cm.*	*Difference in height of mercury level* (h) *in cm.*	*Pressure acting on enclosed air in cm.* $(P=A\pm h)$	*Volume of enclosed air* (C) *in c.c.*	*Total Pressure* $\times$ *Volume* $(P\times V)$

Fill in the table with a series of readings with the right hand tube raised and lowered with respect to the left-hand tube and calculate the relation between the volume of the gas and the corresponding pressure acting on it.

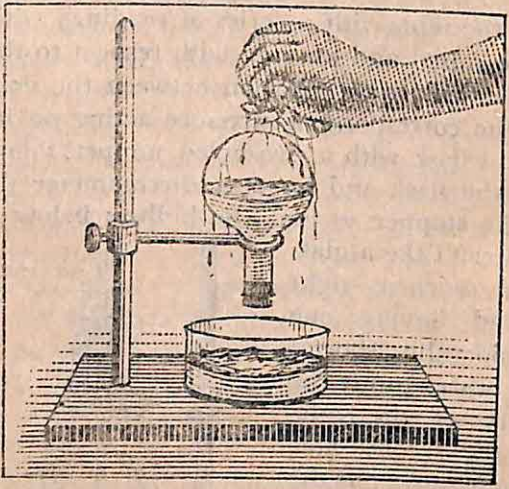
10. Fit a flask with a two-holed stopper. Pour some pure water in the flask and insert a thermometer through one hole of the stopper so that the bulb is below the surface of the water. Take a glass tube bent twice at right angles and having one arm considerably shorter than the other. Insert the short arm of the tube through the second hole of the stopper and put the long arm into an empty measuring cylinder. Heat the water and note the temperature at which it boils. After the water has been boiling for a while pour some mercury into the cylinder so that the steam issuing from the tube will bubble through the mercury. The pressure



The arrangement to find the effect of increased pressure on the boiling point of water.

under which steam is forced out of the flask is now increased. With the addition of more mercury in the cylinder the pressure will be further increased and this will be shown in the corresponding rise of the boiling point.

11. Take a round-bottomed flask and half-fill it with water. Heat the flask and as soon as the water boils freely, quickly stopper with a cork. The flask now contains water and vapour. Since almost all the air in the flask has been driven off by the steam there is hardly any air pressure acting on the surface of the water. There is, however, the pressure of the vapour acting on the water surface. Invert the flask and cool it by holding it under a stream of water. Some of the vapour in the flask will condense and there will now be less vapour pressing on the surface. This decrease in pressure results in the water boiling at a temperature below its normal boiling point.



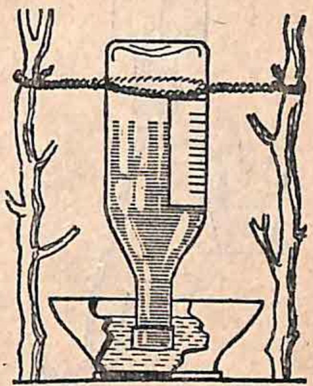
Water boiling under reduced pressure.

At home

Make these models.

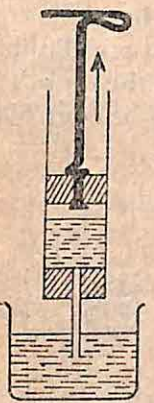
1. Obtain a bottle with a narrow neck to make your own barometer. Fill the bottle partly with water and invert it over a shallow trough of water so that the lower portion of its neck is immersed in the water. Support the bottle as shown in the picture.

When the humidity of the air outside is high, the air becomes lighter, and the level of water in the bottle will fall. If, however, the air outside is dry it becomes heavier and the level of water in the bottle will rise. The variations in atmospheric pressure can be recorded approximately on a strip of paper gummed to the outside surface of the bottle.



A home-made barometer.

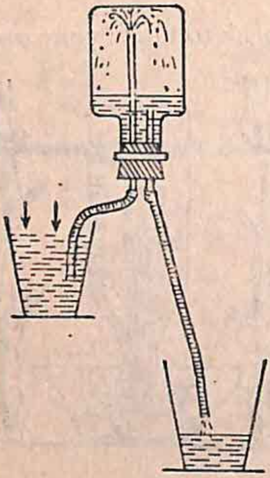
2. Assemble a syringe using glass tubing, two corks and a piece of metal rod as shown. The lower cork can be made air-tight with wax while the cork used for the piston can be made air-tight by wrapping string around it.



A home-made syringe. The arrow shows the direction in which the piston moves.

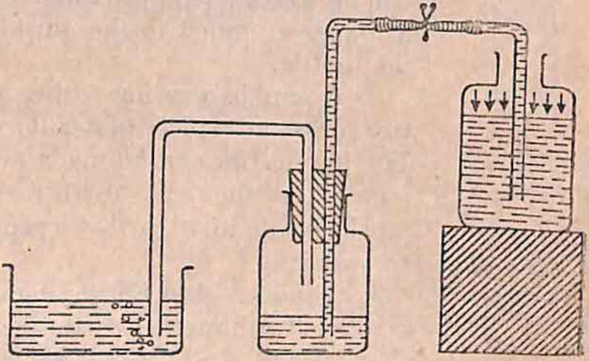
3. Obtain a glass bottle, two tumblers, a two-holed stopper, two rubber tubes, a glass jet and a glass tube. Pour some water into the glass bottle and insert the stopper with the glass tubes. Be sure that the jet

is at a higher level inside the bottle than the other glass tube. Invert the bottle, having arranged the rubber tubes as shown. Try to explain the action of the siphon you have made.



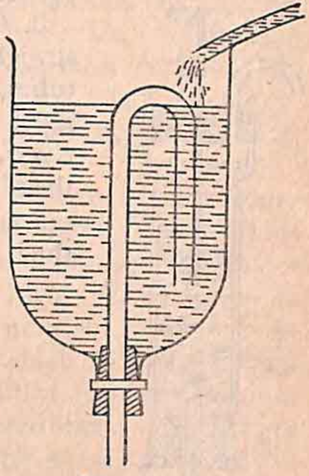
A fountain in a bottle. Arrows show the direction of air pressure.

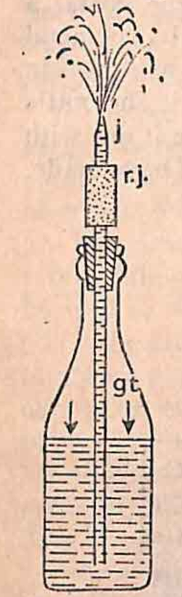
4. If you have an aquarium at home you can fit together the following pieces of apparatus as shown in the diagram to help you aerate the water in the tank. You will need two large bottles, three bent glass tubes, a short piece of rubber tubing, a two-holed stopper and a clip. As the water siphons from the jar on the right it flows into the next jar displacing the air it contains. The displaced air bubbles through the water in the tank. The rate of siphoning can be controlled by means of the clip.



A simple aerator.
Arrows show the direction of air pressure.

5. This model of an intermittent siphon is an application of the principle of a siphon. Take a bell jar, a one-holed stopper and a tube bent as shown in the diagram. Fit the siphon to the inside of the bell jar and pour water into the jar. When the water rises to a level just over the glass tube it flows out of the tube in a powerful gush till the level falls below the open end of the siphon tube.


A tantalus cup.



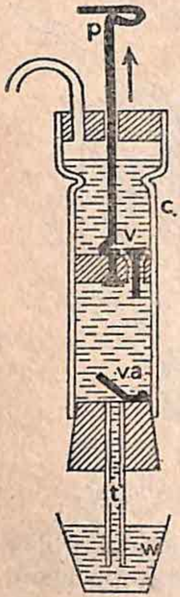
How compressed air can be used to make a gusher. Arrows show the direction of air pressure. j, jet; r.j., rubber joint; g. t., glass tube.

6. Obtain a glass jet, a short piece of rubber tubing, a glass tube, a one-holed stopper and a bottle. Connect the jet and the glass tube with the help of the rubber tube. Fit the jet through the stopper as shown. Pour some water into the bottle and firmly insert the stopper. Hold the stopper firmly in place and blow hard down the jet into the bottle. Point the bottle away from you and note what happens. Can you explain the result?

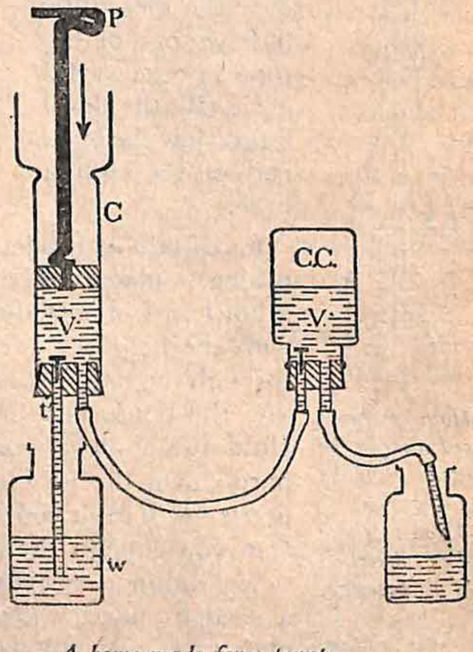
7. Obtain a straight-sided lamp chimney, a straight narrow glass tube, a bent narrow glass tube, a metal rivet, three corks, a piece of wire, a small piece of leather, a drawing pin and a tumbler. Fit the parts together as shown in the diagram to make a simple lift pump. Pour some water

into the tumbler and try to draw it out with the help of the lift pump you have made.

8. Obtain a straight lamp chimney, four straight narrow glass tubes, two rubber tubes, three glass bottles, three corks, a piece of wire, a glass jet, and two metal rivets. Fit these parts together as shown in the diagram. Pour some water in the bottle marked 'well' and try to draw it out with the help of the force pump you have made.



A home-made lift pump. Arrow shows the direction in which the piston moves. c, cylinder (lamp chimney); p, piston (wire); t, glass tube; v, piston valve (metal rivet); va., foot valve (leather disc); w, 'well' (tumbler of water).



A home-made force pump.
Arrows show the direction in which the piston moves. c, cylinder (lamp chimney); c.c., compressed air chamber (glass jar); p, piston (wire); t, glass tube; v, valves (metal rivets); w, 'well' (jar of water).

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces : pressure cooker, barometer, altitude, valves, directions, weight, levers, pressure, air, area, boiling point, Boyle's, height, mercury, surface, temperature, aneroid, thirty, weather, raises, volume, water, increase, thirty-four, decrease, pumps, box, lowers, dial, vessel, syringes, pointer.

Air exerts—equally in all—. The pressure of air on any given—is equal to the—of the column of air above. This column of air will balance a column of—about—inches high and a column of—about—feet high. The simple—is an instrument which measures atmospheric pressure in terms of the—of a column of mercury which can be supported by it. The—barometer magnifies small movements produced on the surface of a partially evacuated metal—by changes of atmospheric pressure. These changes are magnified by—and read by a—which moves over a graduated—. Barometers are used for measuring pressure,—and changes in—. —and—are worked by atmospheric pressure. The arrangement of—inside a pump determines the direction of the flow of—from a—to which the pump is connected.

—law states that the—of a given quantity of gas at constant—is inversely proportional to the pressure to which it is subjected.

Variations in atmospheric pressure affect the—of a liquid. An—of pressure above the—of a liquid—the boiling point of the liquid while a—in pressure—it. The—is based on this principle.

CHAPTER II

PRESSURE IN LIQUIDS

ALTHOUGH this chapter and the next deal chiefly with liquids it will be necessary before we proceed further to examine a few of the principal differences between the properties of the three states of matter—solids, liquids and gases.

The chief difference between the various states of matter depends on the closeness with which the constituent particles are packed together. The force of attraction which binds the particles together is called the force of cohesion. This force is strongest in the case of solids, less in liquids and negligible in the case of gases. On account of this, a solid resists any attempt to alter its shape and the particles composing the solid can only be separated by exerting force. On the other hand, the particles comprising a liquid or a gas are able to move about freely; they slip and slide over each other easily, and can be separated from one another without any difficulty. Furthermore, since the force of cohesion between the particles in the case of solids is much stronger, solids are able to preserve a definite shape and volume, whereas liquids and gases take the shape of the vessel into which they are put. Unlike a gas, however, a liquid preserves its volume. If a liquid is poured into a vessel it occupies only a certain portion of the space inside the vessel, and although its shape will vary according to the shape of the different vessels into which it is poured, it will always occupy the same space. If a gas is admitted into a vessel, it spreads out and occupies the whole of the space in which it enters. Liquids and gases are classified under the term 'fluids' because of the freedom of movement of their particles which enables them if unopposed to flow easily from one place to another.

We may thus summarise the above properties by saying that a solid has a fixed shape and a fixed volume, a liquid does not have a fixed shape but it has a fixed volume, a gas has neither a fixed shape nor a fixed volume.

Force and Pressure. These two words are often given the same meaning in everyday speech, but in science each is defined exactly and given a distinctive meaning.

We have already mentioned the term 'force' in connection with weight, which is the force of attraction which the earth exerts upon a body; also, in connection with cohesion, which is the force with which particles of matter attract one another.

A horse pulling a carriage along the road is exerting a force, so also is a boy pulling a desk over the floor. These examples make it clear that a force is that which changes the state of rest of a body.

A body does not always move, however, when acted on by a force. In the examples cited above, a horse pulling hard at a heavily laden carriage may fail to move it, and a boy pushing hard against a very heavy desk may not succeed in moving it. So we must enlarge our definition of force to read, 'Force is that which changes, or tends to change, the state of rest of a body.'

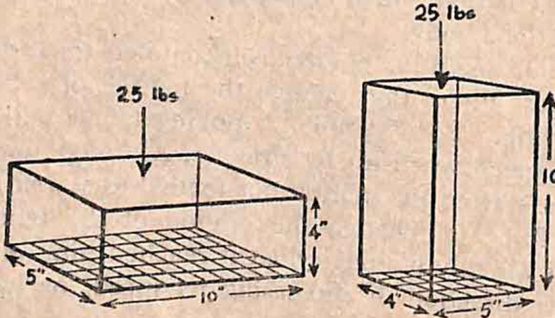
As yet, our definition of force is incomplete for it does not include those forces that change the motion of a body already moving. For example, a moving tennis ball has its motion changed when hit by a player. Although the player has neither started the motion nor tended to start it, yet he has used force to change the motion of the tennis ball which was already moving when it reached him, either by altering its direction or increasing its speed, or by doing both.

A force does not only produce motion but can also stop motion. Thus the motion of a cricket ball stops abruptly when seized by a player. A final definition of 'Force' which includes all the points mentioned will now read, 'Force is that which changes, or tends to change the state of rest or motion of a body'.

Consider a rectangular solid block, weighing say 25 lb. and measuring 10 in. long, 5 in. wide and 4 in. deep. When laid on a table the total downward force, or 'thrust' exerted on the table is 25 lb., irrespective of the face which makes contact with the table. It is evident, however, that this force of 25 lb. may be distributed over 20 sq. in., 40 sq. in., and 50 sq. in., depending on which face of the block makes contact with the table. We can express the distribution of the force by calculating how much of it acts on each unit of area. By doing this we will be making a statement of the pressure, which is defined as the force per unit area.

In the British system of measurement, pressure is evaluated in oz. weight per sq. in., lb. weight per sq. in., or lb. weight per sq. ft. In the Metric system of measurement, pressure is evaluated in gm. weight per sq. cm.

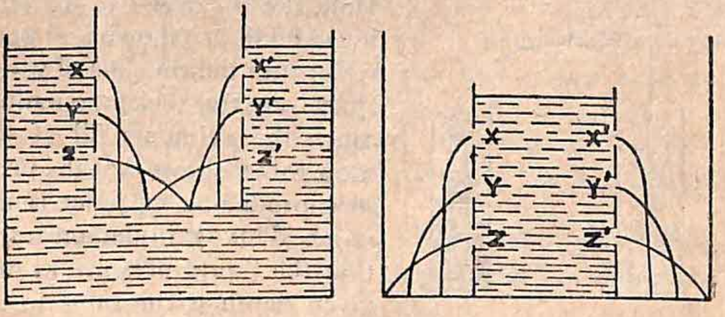
In the example given, let us suppose that the largest face



The pressure exerted by the block in each of the two positions is different.
Left: pressure-½ lb. per sq. in.
Right: pressure-1¼ lb. per sq. in.

of the block is in contact with the table. The force exerted by the block on the table is 25 lb. which is distributed in this position over an area of 50 sq. in. Since Pressure $= \frac{\text{force}}{\text{area}}$ the pressure exerted by the block on the table will be $\frac{25}{50}$ or $\frac{1}{2}$ lb. per sq. in. When the block is stood on end, the force it exerts is still 25 lb. but since this force is now distributed over a smaller area, i.e. 20 sq. in. the pressure has increased to $\frac{25}{20}$ or $1\frac{1}{4}$ lb. per sq. in. It is, therefore, evident that a large pressure results from the application of forces over relatively small areas.

Pressure in Liquids. Drill a hole in the bottom of a tin and pour some water into it. A jet of water immediately rushes downwards through the hole showing that the pressure exerted by water is in a downward direction. When the tin is empty, push it into a trough of water keeping it in an upright position. As you force the tin downwards, a jet of water rushes upwards through the hole showing that the pressure exerted by the water in the trough is in an upward direction.

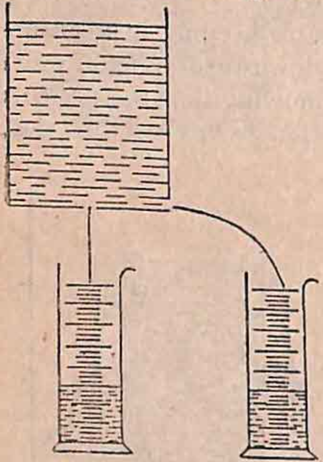


To show that a liquid exerts pressure in all directions and that the pressure increases with depth.

The lateral pressure exerted by water can be demonstrated as follows. Drill six holes of the same size in the sides of a tin so that each pair of holes, i.e. xx', yy', zz', is on the same horizontal level. Press the tin into a trough of water keeping it in an upright position and take note of the jets of water that spurt into the tin. It is seen that the jets starting from holes at the same level reach the bottom at the same distance from the side. This shows clearly that the lateral pressure by the water all round the tin is the same at all points at the same level below the surface of the water, and is the same in all directions. Since the lower the holes the further the jets extend, it follows that the pressure inside a liquid increases with the depth below the surface. This is to be expected, as at the level of any hole, water is pressed downwards and sideways by the water above it.

If the tin is placed in an empty trough and filled with water, the outward lateral pressure of water can be demonstrated in a similar manner as above.

Take another tin and drill a hole in its side, just near the bottom, and another of the same size in the centre of the bottom. Hold the tin over two measuring cylinders as shown and pour water into the tin. Jets of water spurt out from each opening. Since the cylinders fill at the same rate it shows that the pressure producing each jet is the same. This again demonstrates that the liquid pressure at any given depth is the same in all directions.

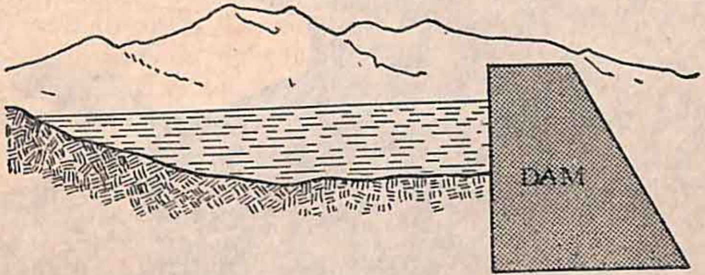


To show that the pressure exerted by a liquid at any given depth is the same in all directions.

We may sum up what we

have just learnt by saying that the pressure at any point in a liquid is the same at the same level, increases with the depth, and is exerted equally in all directions.

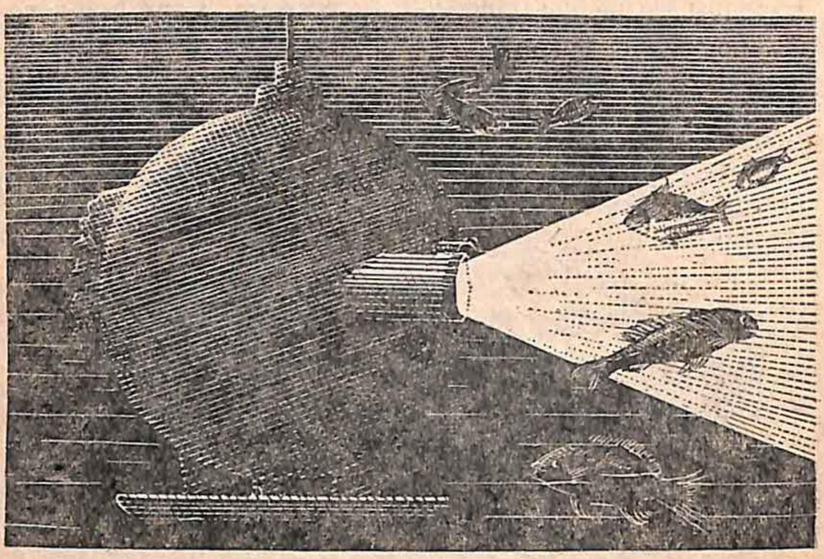
Engineers when constructing a dam take into consideration the fact that the pressure exerted by water increases with the depth below its surface. They make the dam broader at the base in order to withstand the greater pressure of the water at the bottom of the reservoir. Divers, working at very great depths below the water, are protected against the effects of the high pressure of the water at these depths by wearing steel diving suits with steel joints to allow for movements of the limbs. For work in fairly shallow water, the diver wears a rubber diving suit into which air is supplied at a pressure corresponding to the depth at which the diver works. Observational work within the sea is done in a very strong steel sphere with small thick glass windows, called a bathysphere.



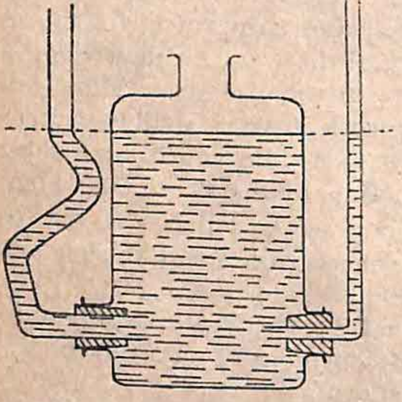
A dam is built wider towards the base to withstand the pressure of the water.

Water Seeks its Own Level. Fit two bent glass tubes of different bore through the side openings of an aspirator by means of rubber stoppers as shown.

Pour water into the aspirator and note the level at which water stands in each of the glass tubes. You will see that



A bathysphere.



To show that a liquid always seeks its own level.

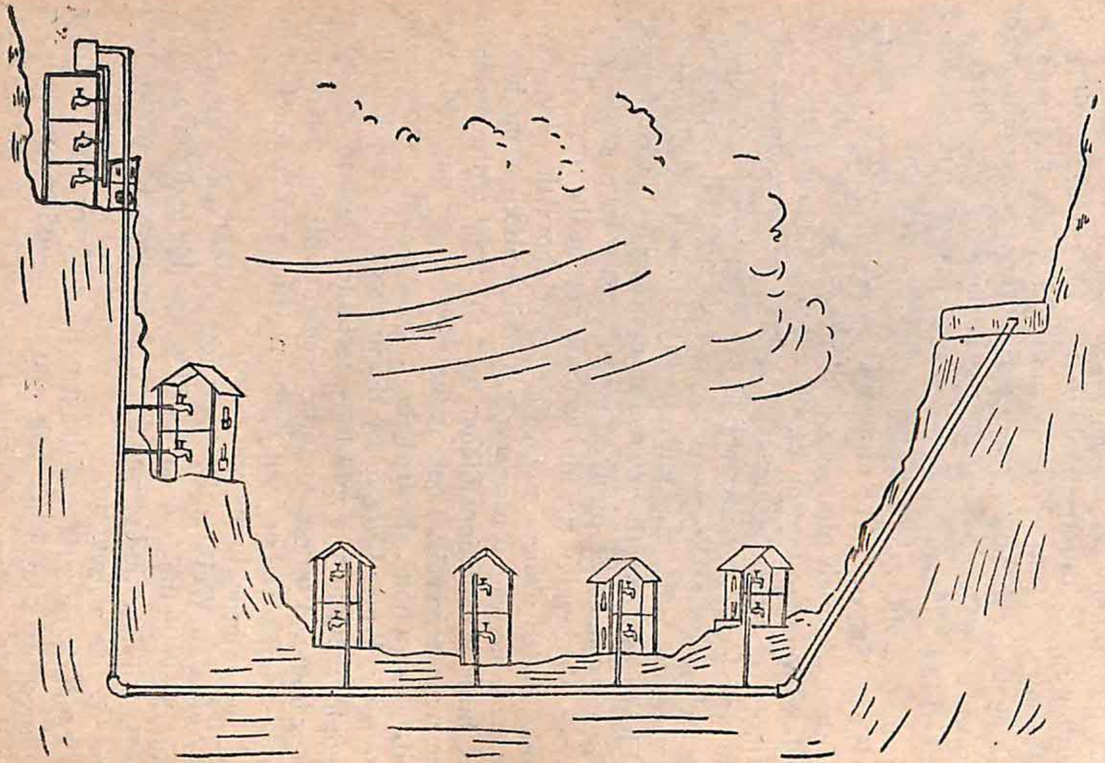
although the weight of water in the aspirator is far greater than that in either of the tubes, this weight cannot force the water in the tubes to a level higher than the level of water in the aspirator. If the tubes are exchanged for others of different shape and bore, it will be seen that the final levels in all three columns will be the same.

Since the pressure at any point depends on the depth of the point below the free surface of the liquid, the pressure at all points within the liquid in the same horizontal plane, in all three vessels, must be the same. Therefore the height to which each column of water rises is governed by conditions of pressure within the vessel and not by the weight of water contained in it. The fact that a liquid always seeks its own level has many applications, a few of which we will now consider.

Water Supply. The supply of water for a town is usually obtained through pipes leading from a reservoir built at a higher level than that of the town itself. Since the surfaces of a liquid connected by means of a pipe always attempt to seek the same level, the water will be available at all places which are below the level of water in the reservoir. If the surrounding country is flat it is not practicable to build a reservoir at a higher level than the town. In such cases water from a well of a river must be pumped up to large storage tanks built above the level of the highest buildings in the town. These tanks, called water towers, that tower above the city, serve in the same way as a reservoir. In hill-stations, some houses are built at elevations higher than the level of the water in the main reservoir. Look at the diagram on page 46. You will notice a house situated above the level of the water in the reservoir. Water brought by the pipes cannot reach it. The people living here would have to build a cistern on top of their house. A pump would be needed to fill the cistern with water from a well or from a cistern which can be reached by the water brought by the pipes.

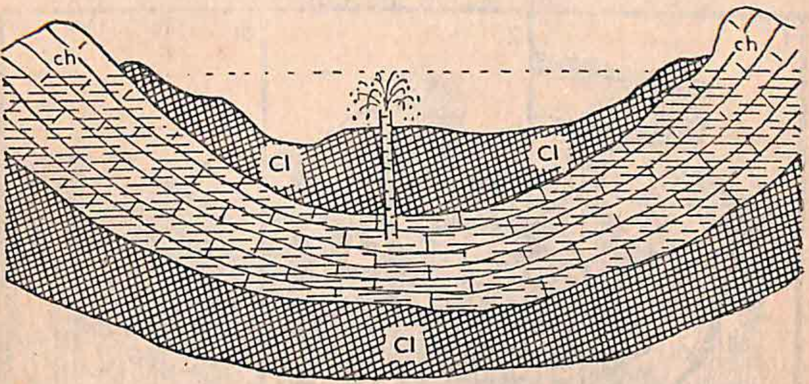
Artesian Well. If the formation of the land is similar to that shown in the diagram it will be possible to dig an artesian well. This is a kind of well from which the water squirts into the air like a fountain.

Beneath the surface of the ground is a layer of rock or clay followed by a layer of chalk, and then another layer of rock or clay. If the layer of chalk is exposed at the outer edges,



The city water supply.

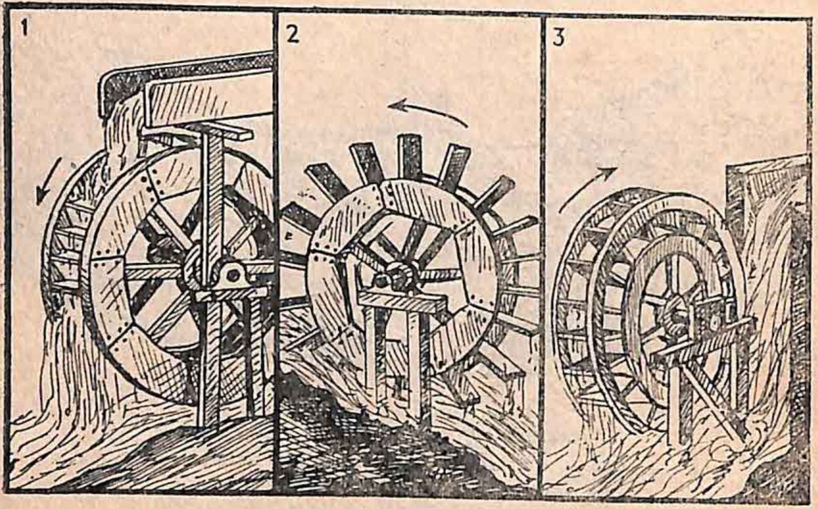
the rain which falls on the ground soaks through these edges. Since no water can pass through the impermeable layer of clay or rock, the water collects in the porous layer of chalk as though it were a large basin. If a well is now dug through the top layer down into the waterlogged layer, so that it is below the water level in the basin, then water will gush up the well like a fountain in an attempt to seek its own level. If, however, the level of the water in the basin is lower than the mouth of the well, the water will have to be pumped out, in which case it is no longer an artesian well.



Section of an artesian well.
The broken line shows the water level.
ch., layer of chalk; cl., layer of clay.

Water Power Machines. From earliest times, man has utilised the energy possessed by water by virtue of its velocity and its pressure for the performance of useful work. The overshot, undershot and breast types of waterwheel were once widely used for this purpose.

In the overshot type of wheel, the water flows over the top of the wheel and the weight of the water in the buckets fastened all around the rim provides the force to turn the wheel. In the undershot wheel, the swift movement of water flowing under the wheel rotates it. Rotation of the breast wheel is brought about by a combination of the forces that turned the other two types.

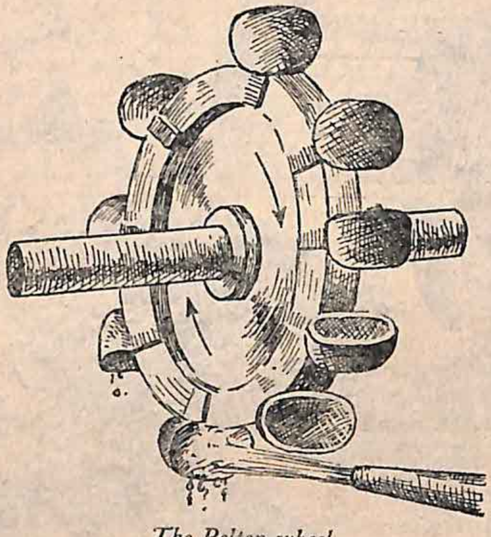


Waterwheels.
The arrows show the direction in which the wheels move.
1. *Overshot.* 2. *Undershot.* 3. *Breast.*

Waterwheels are seldom used nowadays, because they waste a large amount of the available energy and are not suitable for developing high power.

The modern version of the waterwheel is the turbine, in which the blades around the rim of the wheel and the way of directing the water on the blades are so arranged as to extract from the water the largest possible amount of the energy available.

One such type is the Pelton wheel which is made of metal and has a number of bucket-shaped metal blades built around its rim. Water from a dam is conducted to the wheel by means of a pipe. Since the dam is at a considerable elevation above the wheel, the water brought to the wheel is at a very high pressure. The powerful jet of water issuing from the pipe is directed against the buckets and causes the wheel to rotate rapidly.

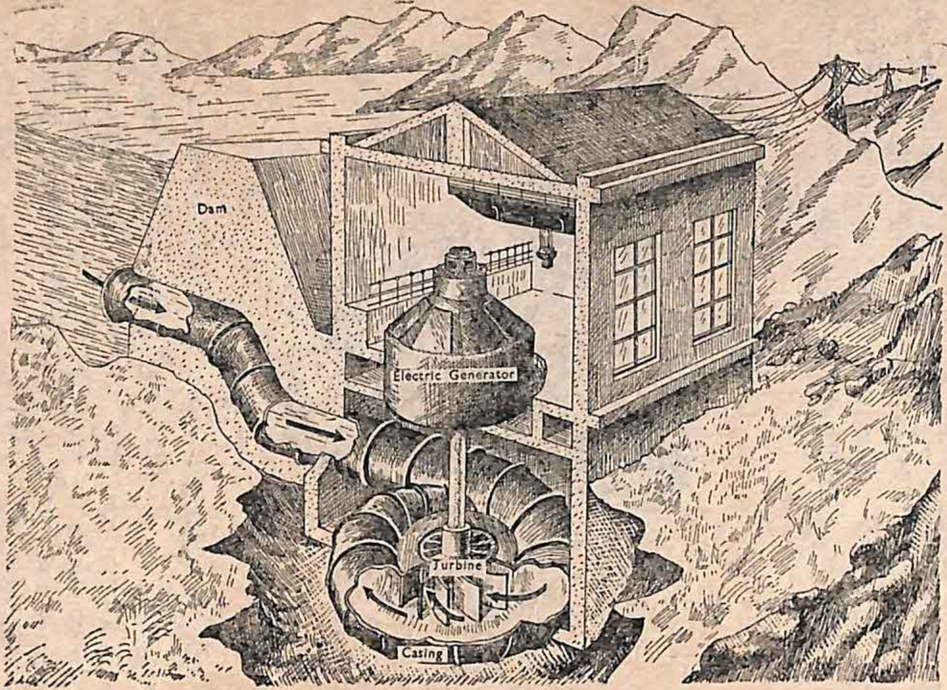


The Pelton wheel.

The arrows show the direction in which the wheel moves.

Another type is the Reaction turbine, in which the water, under pressure, enters and entirely fills the turbine casing and is then guided by vanes attached to the casing against the blades of the rotating wheel, which is thus set in motion by the pressure of the water.

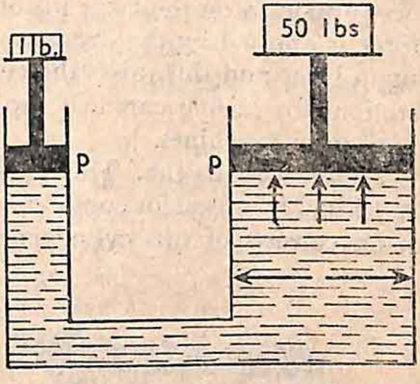
The Pelton wheel requiring a very fast flow is preferable with very high water heads; the Reaction turbine is better suited for lower water heads. Both kinds of turbines are used



A hydro-electric plant.
The arrows show the direction in which the water flows. The vanes attached to the casing are not shown in the picture.

to rotate the shaft of an electric generator, supplying electric power to neighbouring towns.

Multiplication of Fluid Pressure. Consider two cylinders of different cross-sectional areas connected to each other by a side tube. The cylinders are filled with water and are provided with water-tight pistons. Suppose the cross-sectional area of the narrow cylinder is 1 sq. in. and that of the other is 50 sq. in. Now if a weight of 1 lb. is placed on the piston, the force exerted on the piston is that exerted by a 1 lb. weight. As this force is distributed over 1 sq. in. the pressure applied by the piston is 1 lb. per sq. in. This vertical pressure is transmitted to the water as a lateral pressure exerted along the sides of both cylinders and communicating tube, as well as a vertical pressure in an upward direction against the piston with the larger area. On each square inch of the lower surface of this piston, there is an upward push of 1 lb. and since the cross-sectional area of this piston is 50 sq. in. the total force exerted on the piston is 50 lb. A 50 lb. weight can, therefore, be balanced by a small force of 1 lb., since the total upward force exerted on the larger piston is fifty times the downward force applied to the smaller piston.

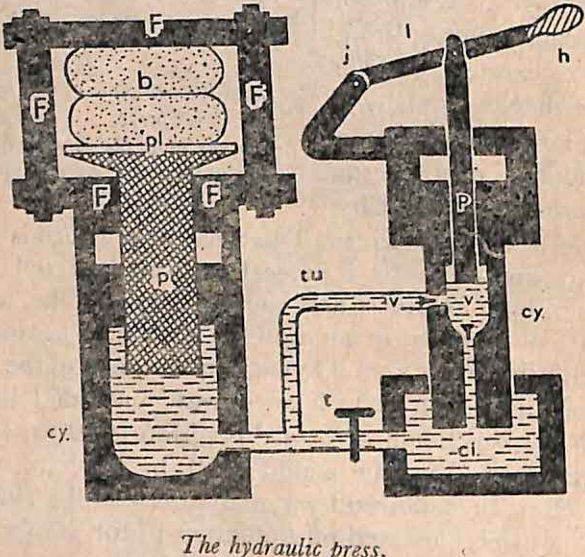


To show the principle of the hydraulic press.
The arrows show the direction of the pressure exerted by the liquid.
p, piston.

The principle of multiplication of forces by transmission of fluid pressure is applied in designing many machines, called hydraulic machines, which are used for pressing oil from oil seeds, pressing cotton in bales, punching holes in steel and lifting heavy loads.

In some barber and dentist shops you will see chairs which are supported on the large piston of a hydraulic machine. A force is applied by the operator to a small piston by pumping a lever and this raises the chair. The lifts seen in service stations for raising cars are also worked on the principle of hydraulic machines.

Hydraulic Press. This is an example of a hydraulic machine. It is used for compressing large bales of cotton. The press consists of two cylinders provided with tightly fitting



The hydraulic press.
b, bales; ci., cistern; cy., cylinder; f, framework; h, handle; j, joint; l, lever; p, piston; pl., platform; t, tap; tu., connecting tube; v, valves.

pistons and communicating with each other by a pipe. The cross-sectional area of one cylinder is far larger than that of the other. Therefore, a small additional downward force applied to the smaller piston can raise the other with a large force that is proportional to the increase in the area of its cross-section. When the larger piston rises, it raises a platform and the bale of cotton between this platform and the outer framework is compressed.

The smaller cylinder is constructed in the form of a force pump to raise water from the cistern below it and force the water into the larger cylinder through the communicating tube. The pump is worked by a handle which is attached to the smaller piston. Water entering the larger cylinder lifts the piston and compresses the bales placed on it. To bring the piston down, the outlet tap is opened and the water allowed to flow back into the cistern.

Hydraulic Brakes. These brakes are used in most cars. When the brake pedal is pushed forward, pressure is exerted on a liquid in a small cylinder and thence transmitted equally throughout the fluid in the tubes leading to the larger wheel cylinders. The pressure on the fluid in these cylinders forces their respective pistons out which results in applying the braking pressure on the lower rims of the wheel.

CHAPTER ACTIVITIES

Outdoors

1. Visit a dam site. Note that the dam is broader at the base than at the top. If the water stored in the reservoir is used to generate electricity, visit the hydro-electric station and ask to be shown the turbines.

2. Visit a motor-car service station and see the various hydraulic machines that are in use.

For your wall newspaper

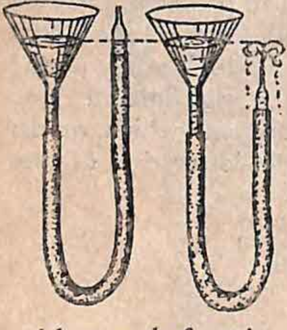
Take photographs of the following: (*a*) a dam, (*b*) a fountain, (*c*) the main pipes bringing the city water supply, (*d*) a water tower, (*e*) a cistern built at the top of a building, (*f*) a hydro-electric power station, (*g*) a car lift, (*h*) a hydraulic jack and (*i*) a hydraulic press. Mount the photographs on your board and write a suitable caption beneath each.

Note-book exercise

Write an essay on how water is made to do useful work in your state.

At home

Have you ever wondered how a fountain works? You can find out easily enough by making your own.

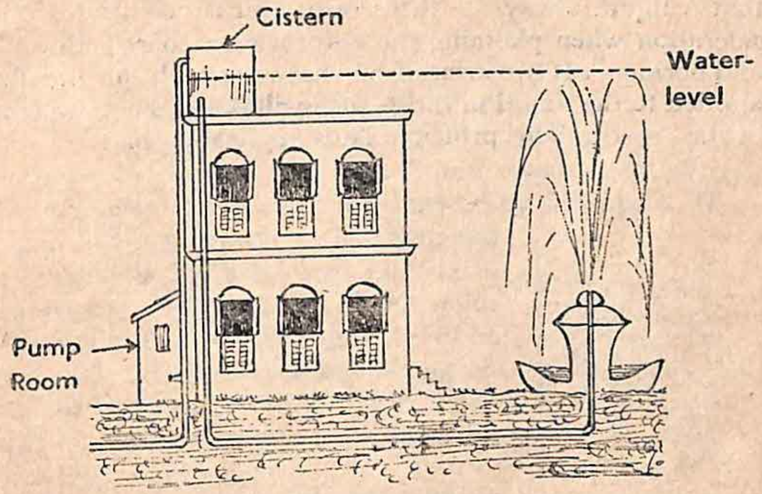


A home-made fountain.

Fit a funnel to one end of a rubber tube and connect the other end to the glass part of a fountain-pen filler. As water is poured into the funnel it rises in the glass jet until it is level with the water in the funnel.

Change the position of the jet, by holding it in each of the two positions. You will find that in whatever position the jet is held, water will always seek its own level.

The fountain in the garden works the same way as this model. The cistern could be compared with the funnel, the pipe to the rubber tube, and the fountain to the jet.



How the garden fountain works.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces: pressure, equally, cohesion, liquid, depth, wider, gas, force, smaller, directions, greater, area, solid, artesian wells, shape, fountains, narrow, cross-sections, volume, rises, hydraulic machines, U-tube, water supply, level.

A— and a — flow easily since their particles, unlike a —, have little —. For this reason they have no — of their own but take the shape of the vessel in which they are contained. A liquid, unlike a gas, has a definite—.

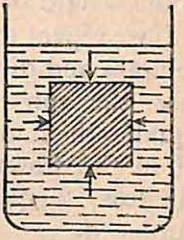
— is defined as that which changes or tends to change the state of rest or motion of a body whereas pressure is defined as the force per unit —.

The — at any point in a liquid is the same at the same —, increases with the — and is exerted — in all — . The fact that a liquid always — to its own level is taken into consideration when planning the — of a city, constructing — and boring—. If two arms of a— have unequal—a —weight applied to the liquid in the — arm will balance a — weight in the — arm. This principle finds application in—.

CHAPTER III

SINKING AND FLOATING

WHEN a solid is immersed in a liquid, every point of its surface is subjected to a pressure exerted by the liquid. The pressure at any point acts at right angles to the surface of the solid and is directly proportional to the depth of the point below the surface of the liquid. It will be shown that all these pressures acting on the solid combine into a resultant thrust which has the tendency to move the solid in an upward direction.



Every point of the surface of the block is subjected to a pressure by the liquid.

Upthrust. Suspend a cube of copper or any other metal, having a volume of 10 c.c., from a spring balance and then gradually immerse it in a beaker containing water. Note that the reading on the balance decreases during the immersion of the solid. After the solid has been completely immersed, no further decrease in the weight of the solid is noted. Evidently, the weight of the solid appears to decrease by this process of immersion. Why should this be so ? It is obvious that the pull of the earth on the solid (i.e., the weight of the solid) has not diminished. Clearly then, it is the liquid that provides some support for the solid although insufficient to keep it afloat. The force supporting the solid is called the upthrust or buoyancy of the liquid; the final reading on the spring balance after the solid is completely immersed is called the apparent weight of the solid, while the difference between the true weight of the solid and its apparent weight measures the upthrust of the liquid for the complete immersion of the solid.

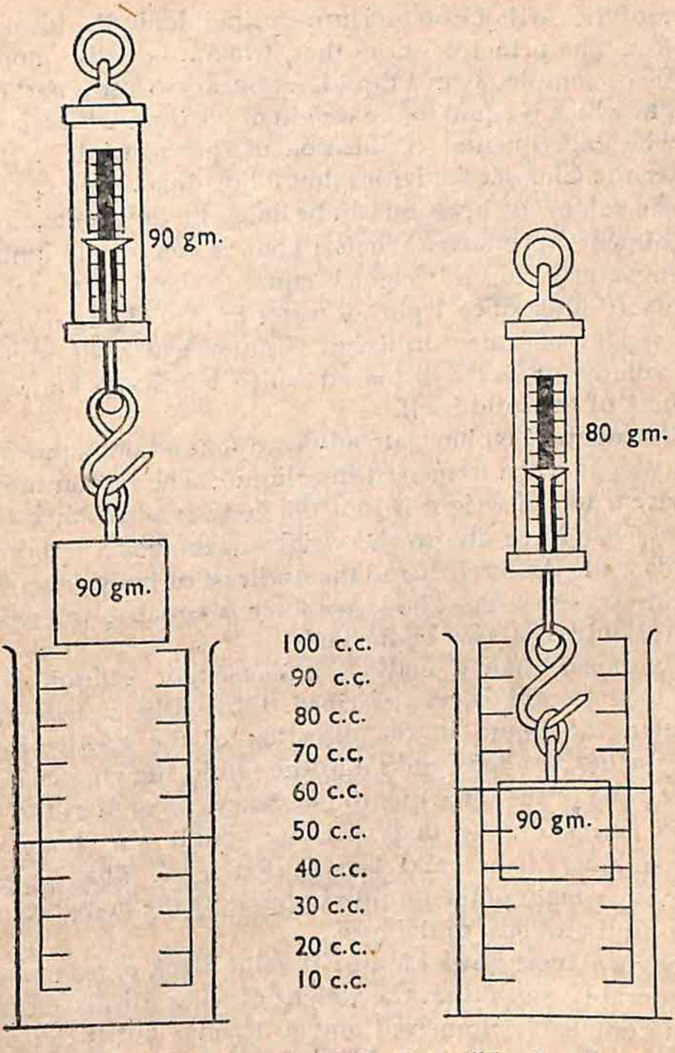
Replace the beaker with a graduated cylinder and fill it with 50 c.c. of water. Now gently immerse the cube of metal and note the volume of liquid displaced. It will be seen that the volume of liquid displaced is 10 c.c. We note that the apparent loss of weight of the cube after it has been completely immersed is 10 gm. Since 1 c.c. of water weighs 1 gm., we conclude that the apparent loss of weight of the solid is equal to the weight of the volume of water displaced by the solid.

If we repeat this experiment using metal blocks of different volumes and different materials, it will be seen that in every case, the apparent loss of weight, measured in grams, is equal to the number of cubic centimetres of the solid immersed in the water, and since 1 c.c. of water weighs 1 gm., the loss is equal to the weight of the volume of water displaced.

If any other liquid is used instead of water we again see that in all cases the apparent loss of weight is equal to the weight of the volume of liquid displaced. In the case of a liquid other than water, however, it must be remembered that a cubic centimetre of the liquid does not weigh one gram.

A solid which floats at the surface of a liquid is completely supported by the liquid and since it appears to lose all its weight we may conclude that the upthrust of the liquid is equal to the true weight of the solid. The volume of the liquid displaced is equal to the volume of that part of the solid which is immersed below the surface of the liquid. It can be experimentally verified that the weight of liquid displaced by the immersed portion of a floating solid is equal to the whole weight of the solid.

Principle of Archimedes. A Greek scientist named Archimedes, who lived in the third century B.C., was the first to determine the exact magnitude of the upthrust of a liquid. The law relating to it, known as the Principle of Archimedes,



To show the apparent loss of weight of a solid when immersed in a liquid.

is one of the earliest exact scientific principles in the history of science. The principle states that, when a body is immersed partly or completely in a liquid, it appears to lose a part of its weight which is equal to the weight of the liquid displaced by it. The experimental verification of the principle is given under the Chapter Activities that follow this chapter.

The volume of any solid can be found by the application of Archimedes' principle. When a body is completely immersed in water its loss of weight is equal to the weight of water displaced and, since 1 gm. of water has a volume of 1 c.c., the weight of water displaced is numerically the same as the volume of water displaced which is, as you know, the volume of the solid itself.

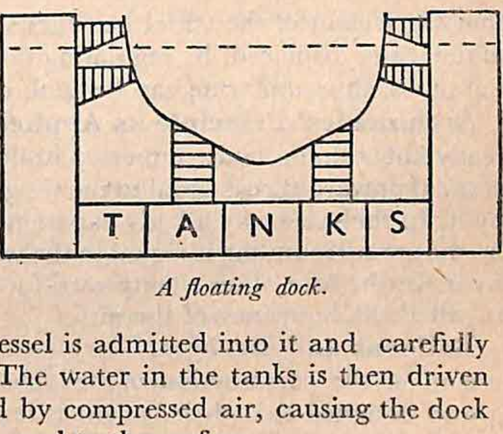
Flotation. You have already read that a body appears to lose weight when immersed in a liquid. The reason for this apparent loss of weight is that the body is acted on by two forces. The force due to the weight of the body acts downwards while the force due to the upthrust or buoyancy of the liquid acts upwards. The latter force is equal to the weight of the liquid displaced by the body.

No sooner than a body is immersed in a liquid, it is acted on by the forces described. Obviously, it will move through the liquid in the direction of the greater force. The further the body sinks into the liquid the greater is the magnitude of the force due to buoyancy. As soon as the two forces acting on the body become equal, the body will stop sinking further and float at that level. This happens when the weight of the liquid displaced by the body becomes equal to the weight of the body.

Why an Iron Ship Floats. A solid block of iron weighs considerably more than the weight of water displaced by it when completely immersed and so it sinks but if the same block is rolled into sheets which are joined into the shape of a ship so that the weight of the water displaced by the immersed portion of the iron is equal to the weight of the iron then the iron will float.

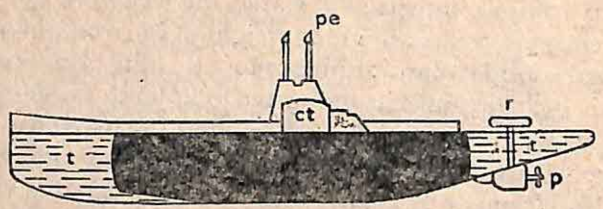
When a ship is immersed in water, the weight of the water displaced is far greater than the weight of the iron immersed, and since a solid cannot displace more than its own weight of a liquid, the ship sinks in the water to a depth at which the weight of water displaced by it is equal to its own weight together with that of its contents. When we say that a ship has a displacement of 20,000 tons we mean that the weight of the loaded ship is 20,000 tons and therefore the weight of water it displaces is 20,000 tons.

The Floating Dock. This is an immense rectangular raft with walls rising from the two long sides of the raft. The walls of the entire contrivance are divided into tanks. The dock is submerged first to the required depth by admitting sea-water into the tanks. After this is done a vessel is admitted into it and carefully propped in position. The water in the tanks is then driven out by pumps worked by compressed air, causing the dock to rise and bring the vessel to the surface.



A floating dock.

The Submarine. This vessel can remain on the surface of the water or sink as desired. It is equipped with tanks which are fitted with valves through which water may enter. The water so admitted can be expelled by means of powerful pumps worked by compressed air. When it is necessary to submerge the vessel, water is admitted to the tanks so that the total weight of the vessel becomes greater than that of the weight of the water displaced. If it is desired to bring the vessel to the surface, water is pumped out of the tanks so that the weight of the vessel becomes slightly less than that of the water displaced. By regulating the inflow of water into the tanks, the submarine can be sunk to various depths.



Section of a submarine.
c.t., conning tower; p, propeller; pe., periscope; r, vertical rudder; t, water tanks.

Archimedes' Principle as Applied to Gases. You already know that a body immersed in liquid is subjected to a vertical upward thrust equal to the weight of liquid displaced by it. In the same way a body experiences an upward thrust by the gas surrounding it, equal to the weight of gas displaced by it. In the case of air the upward force exerted on a body is called the buoyancy of the air.

Balloons and Airships. The buoyancy of the air is made use of in the construction of balloons and airships. These are so designed that their weight is less than the volume of the surrounding air which they displace.

A balloon is merely a large bag of silk or some other kind of light material. This material is varnished so as to ensure that it is airtight. A light car is attached to the balloon by means of ropes. The balloon is filled with a gas which is lighter than air such as hydrogen or helium. The latter is more commonly used for this purpose because it is not inflammable. If the gas contained in the balloon is allowed to escape, the weight of the balloon and its accessories is more than that of the displaced air and the balloon consequently descends. A cord attached to a safety valve offers a means of letting gas out of the balloon. In the car are a number of bags of sand which, if emptied, help the balloon to ascend further or lessen the speed of descent. Balloons are not satisfactory for transporting passengers or freight since they are at the mercy of air currents. They are used, however, by meteorologists and also by scientists engaged in high altitude research.

An airship is very similar in construction to the balloon. It has, however, accessory arrangements to steer the contrivance and vary the speed. Propellers worked by motors are fitted to an airship in order to drive it forward through the air.

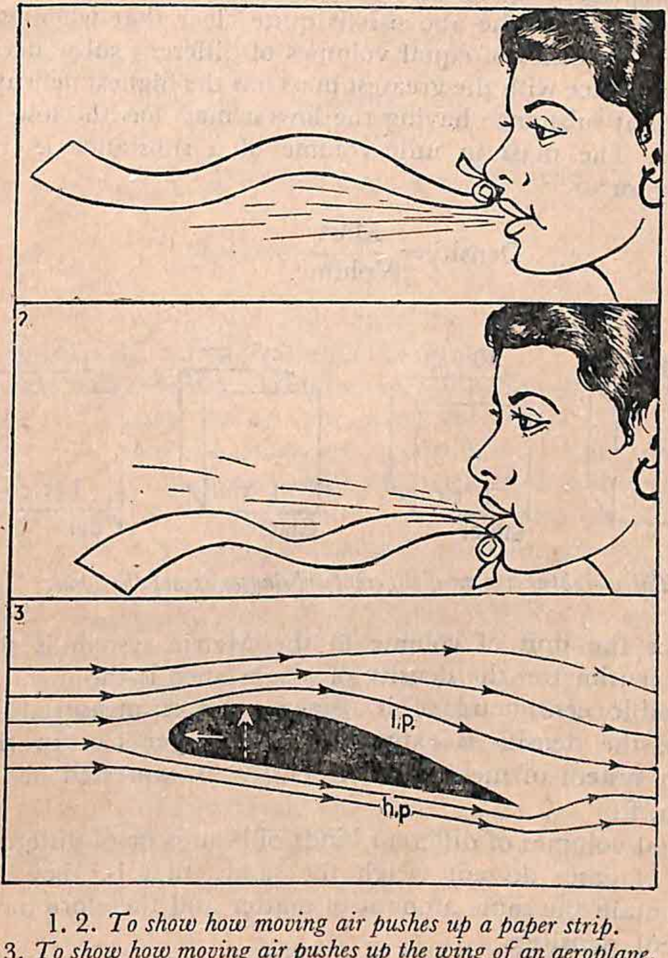
Airships are used to carry passengers for observational and advertising work.

Aeroplanes. Since the weight of an aeroplane is much greater than the weight of air it displaces, it does not come into the same category as that of floating bodies. The action of an aeroplane is determined by the fact that, if a flat surface which is slightly tilted out of the horizontal is driven through the air with the higher edge in front, then the entire surface experiences an upward force or lift.

Hold the end of a long narrow paper strip with a finger under your nose and blow hard. The air you blow strikes the paper and forces it upwards. Now hold the strip against your chin and blow hard. You will be surprised to notice that the paper strip rises again. When you blow across the top surface of the strip the air above this surface moves faster than the air beneath. Consequently, the pressure of the air above the strip is less than the pressure of the air below the strip. The differences in pressures between the air above the paper strip and that of the air below it are thus responsible for raising it. So also, the differences in pressures between the air above the wing of an aeroplane in motion and that of the air below it are responsible for providing the lift of the plane, that is, the force which raises the plane in the air.

An aeroplane is pulled forward through the air by the action of its propellers, but these contrivances are by no means responsible for lifting the plane into the air nor for causing the air currents that blow over the wing. The shape of the wing as seen in cross-section is such that when the plane moves forward through the air, the air above the wing moves faster than the air below it. As a result a region of low pressure forms on the top surface and atmospheric pressure pushes up under the wing and, in doing so, produces most of the force required to raise the plane in the air. Although the difference in air pressure above and below the wing is chiefly responsible for the lift of the plane, about one-third of the lift comes from the impact of moving air against the lower surface of the wing. A pilot always takes off and lands against the wind in order to obtain the greatest possible lift at the slowest possible speed of his plane. Once the plane has been raised into the air, it will remain in the air as long as the lift or upward force is greater than the force due to the entire weight of the plane.

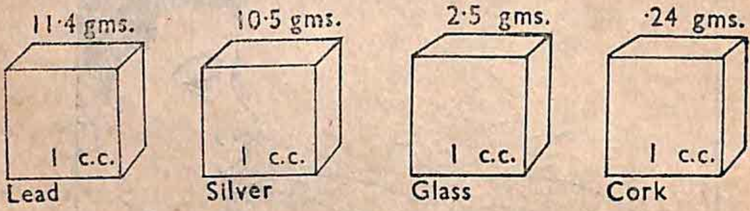
Density. It is often noticed that when equal volumes of two different substances are taken and the masses of each compared by weighing, the masses are different. For example, a cubic centimetre of lead weighs 11·4 gms. while a cubic centimetre of cork weighs ·24 gm. Bulk for bulk then, lead may be said to be heavier than cork. This being so, it must follow that a unit volume of lead contains more matter than a unit volume of cork. Furthermore, the matter contained in the lump of lead is packed more closely together than in the case of the cork. We



1. 2. *To show how moving air pushes up a paper strip.*
3. *To show how moving air pushes up the wing of an aeroplane.*
Black arrows show the direction of the flow of moving air.
Broken white arrow shows the direction of the resulting uplift from reduced pressure above the wing and the impact of air against its lower surface.
Unbroken white arrow shows the direction in which the wings moves.
l. p., low pressure region; h.p., high pressure region.

usually speak of such facts by saying that lead is more dense than cork. From the above it is quite clear that when we compare densities of equal volumes of different substances, that substance with the greatest mass has the highest density, while that substance having the lowest mass has the lowest density. The mass in unit volume of a substance is its density or:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$



The weight of 1 c.c. of different substances is not the same.

Since the unit of volume in the Metric system is the cubic centimetre, the density of a substance is the mass in one cubic centimetre of it. Since mass is measured in grams, the density is expressed in gm. per c.c. In the British system of measurement density is expressed in lb. per cu. ft.

Equal volumes of different kinds of liquids or of different kinds of gases do not weigh the same, that is, they do not contain the same amount of matter and therefore have different densities.

The density of any substance is different from any other. Thus, if two substances look alike they can be distinguished by determining their density. So also we can tell if a metallic substance is pure or in the form of an alloy by finding the density of the substance and comparing the value obtained with that of the true density of the pure metal.

The formula,

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

can also be expressed as Mass=Density × Volume

or,

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}}$$

So, if any two of the three quantities are known we can determine the third by simple arithmetic.

Relative Density. When we talk about a substance being 'light' or 'heavy' we are not being very exact. By saying that the density of a substance, say lead, is 11·4 gm. per c.c. or 710 lb. per cu. ft. we obtain a better idea of its 'heaviness'. Suppose, however, we choose the density of a certain substance such as water, as a standard and compare the densities of all other substances to it. Then if we are told that, volume for volume, lead is 11·4 times as heavy as water we would obtain a very good idea of the 'heaviness' of lead. The comparison of the density of a solid or liquid with the density of water as standard, is called Relative Density. Properly defined, relative density, also known as specific gravity, is the mass of any volume of a substance compared with the mass of an equal volume of water. (In the case of gases, hydrogen, the lightest gas known, is taken as the standard.)

Thus,

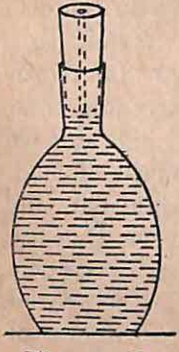
$$\text{Relative Density} = \frac{\text{Density of the substance}}{\text{Density of water}}$$

$$= \frac{\text{Mass of some volume of the substance}}{\text{Mass of equal volume of water}}$$

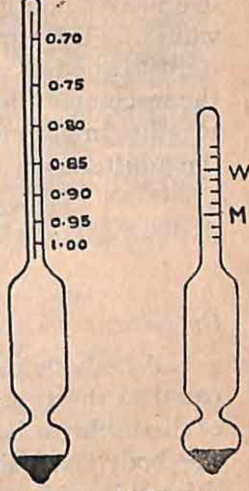
Since the mass of unit volume of water is one gram, the density of water is 1 gm. per c.c. It is evident, therefore, that the number expressing the density of a substance in the units of the metric system and the number expressing the relative density of the same substance is the same. Since relative density is a ratio of two masses, it is always expressed as a number.

Thus when we say that the relative density of lead is 11·4, it is taken for granted that it is 11·4 times heavier than the mass of an equal volume of water. In the British system, the number expressing the density of a substance and the number expressing the relative density of a substance are not the same, as 1 cu. ft. of water does not weigh 1 lb. but 62·4 lb.

Specific gravity bottle. A special vessel called the 'density bottle' or more commonly the 'specific gravity bottle' is used to find the relative density of liquids and of solids available as powders. It is a small, light bottle with a narrow neck. The stopper of the bottle is made of ground glass and has a hole drilled through it. If the bottle is filled to the brim with liquid, and the stopper then put in, the excess liquid is forced through the hole. By this means the bottle is completely filled with liquid. The density bottle helps us to compare the weight of a definite volume of a liquid with the weight of an equal volume of water and thus determine its relative density. So also, the weight of a definite volume of a solid in powdered form can be compared with the weight of an equal volume of water and its relative density determined.


The specific gravity bottle.

Hydrometer. You already know that the depth to which a body floats in a liquid is determined by the weight of the liquid displaced by the immersed part of it equalling the total weight of the body. As different liquids have different densities, it is clear that a body will float at different depths in different liquids. In the case of a liquid with a lower density than water, such as methylated spirit, it is clear that to displace a volume of the liquid of weight equal to its own, the body will have to sink further into the spirit than into the water, If, however, the liquid has a higher density than water such as mercury, the body will sink very slightly as it will not take much of this dense liquid to make up a weight equal to its own.



Left: hydrometer.
Right: lactometer.
M, level for pure milk; W, level for pure water.

The above fact has been applied in the construction of an instrument, called the Hydrometer, which is designed for use in finding the density of a liquid. The instrument is made of glass and consists of a narrow hollow stem graduated along its length and weighted with mercury or lead shot which fills part of a bulb at the bottom. When put into a liquid the hydrometer floats upright, the depth to which it sinks being determined by the density of the liquid—the less the density, the greater the depth to which it sinks. The stem is graduated so that the reading at surface level gives directly the relative density of the liquid in which the instrument is floating, i.e. in water the reading is 1, in methylated spirit 0·8, in milk 1·03 and so on.

Since the densities of liquids vary over a wide range the stem of a hydrometer would have to be inconveniently long. Different forms of hydrometers are, therefore, available for testing the relative densities of various liquids, each instrument being graduated for use over a narrow range of values. The instrument used to test the relative density of milk is called a lactometer. The stem is graduated by putting the instrument into vessels containing milk and water mixed together in various proportions. A lactometer guards against the adulteration of milk with water.

CHAPTER ACTIVITIES

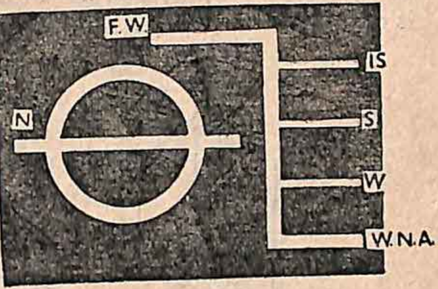
Outdoors

1. A body floats on a liquid if the upthrust of the liquid is equal to the true weight of the body. Since the magnitude of the upthrust is equal to the weight of liquid displaced by the body, and since different liquids have different densities, it is evident that each liquid exerts a different upthrust on a substance, the magnitude of the upthrust depending on the density of the liquid. A liquid that has a high density exerts a greater upthrust on a body than a liquid that has a lower density. It is for this reason that swimmers find it easier to swim in salt water than in fresh water. The density of salt water being higher than that of fresh water, the upthrust of salt water is greater than that of fresh water.

2. If you have an opportunity, visit a dockyard and see how ships are moved in and out of a floating dock.

3. Notice that on the hull of every ship there is a series of lines, known as Plimsoll lines.

You have read in your text that a ship sinks to a depth at which the weight of water displaced by it is equal to its own weight together with that of its contents. It is obvious that the weight of the water displaced will vary according to the load carried by the ship. The Plimsoll lines indicate



Plimsoll line.
N, normal loading line.
F.W., fresh water.
I.S., Indian summer.
S, summer in temperate zones.
W, winter in temperate zones.
W.N.A., winter in North Atlantic.

safe levels to which a loaded ship may be immersed in water. Since the density of sea-water depends on its temperature which, in turn, depends partly on the time of the year and partly on the latitude, an ocean-going vessel can be regarded as a hydrometer. Special lines indicate safety levels for vessels sailing in tropical zones where the sea is less dense than in temperate zones. Moreover, since the density of fresh water is less than that of salt water there is a special level for fresh water.

For your wall newspaper

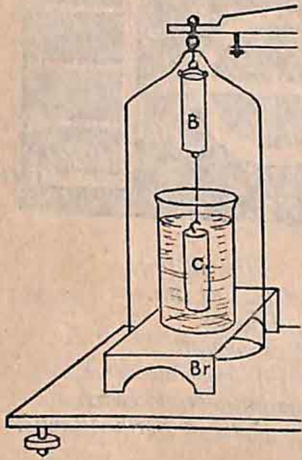
Prepare a chart entitled 'How floating bodies are used to help man'. Collect the following pictures for your chart: different kinds of boats and ships, a floating dock, a submarine, a life buoy, a life belt, a mooring buoy, a marking buoy, a fishing float, a floating bridge, a ball-cock valve, a balloon, an airship, and different kinds of hydrometers.

Note-book exercise

Consult books in your science library and collect enough material to write biographies of Archimedes and Samuel Plimsoll.

Laboratory work

1. Archimedes' principle may be verified experimentally

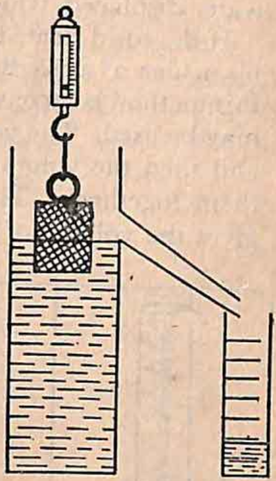


The cylinder and bucket experiment. C, solid cylinder; B, 'bucket' (hollow cylinder); Br.; wooden bridge.

in the laboratory by the use of a hydrostatic balance which is merely an ordinary balance with an arrangement by which a body may be weighed in air and also when immersed in a liquid. Suspend a hollow cylinder from the hook of the left-hand pan of the balance and suspend a solid cylinder below it which fits exactly into the inside of the hollow cylinder. Counterpoise the two cylinders by putting weights on the right-hand pan. Leave the weights on the pan. Next, place a beaker of water on a wooden bridge which spans the left-hand pan so that the solid cylinder is completely immersed. As this is done the water exerts an upthrust on the solid cylinder which causes it to apparently lose weight. By means of a pipette, fill the hollow cylinder with water. You will observe that the balance regains its equilibrium when the cylinder is full of water. Since the volume of the solid cylinder is equal to the internal volume of the hollow cylinder it is evident that the weight of the water in the hollow cylinder corresponds to the apparent loss of weight of the solid cylinder or the upthrust exerted on the solid cylinder by the water in the beaker. Furthermore, the weight of water in the hollow cylinder is evidently the same as the water that would be displaced by the solid cylinder.

2. You will need an overflow vessel and a measuring cylinder to demonstrate that the weight of liquid displaced

by the immersed portion of a floating solid is equal to the loss of weight of the solid. First weigh the solid. Next fill the overflow vessel with water up to the level of the opening and place a measuring cylinder beneath the spout. Gently lower the solid into the water by means of a piece of string and note the volume of water that collects in the measuring cylinder. The volume of water that collects, i.e. the water displaced by the immersed portion of the solid, will be numerically equal to the loss of weight of the solid.



To show that the weight of liquid displaced by a floating solid is equal to its loss of weight.

3. The density of various regular solids may be found by using the formula:

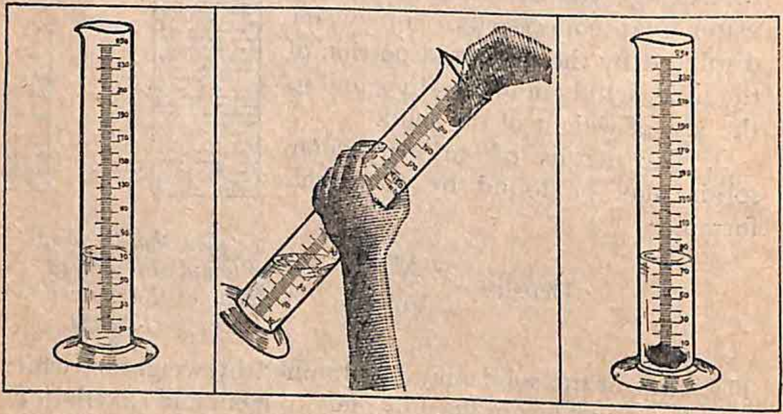
$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The mass of the solid may be obtained by weighing, while its volume may be obtained by measurement and calculation. Remember to express your result in gm. per c.c. Check the densities of the following: Aluminium (2·7); Brass (8·5); Glass (2·5); Silver (10·5).

4. The density of various irregular solids may be found by using the same formula as above. As before the mass of the solid may be found by weighing it. Its volume may be found by the method of displacement. Pour some water into a measuring cylinder and read the volume of water. Now tilt the cylinder and gently slide the given solid into the cylinder. Make sure that the object lies completely below the surface of the water. Note the new readings. The

difference between the two readings gives the volume of water displaced, which is equal to the volume of the solid.

If the solid floats it should be pushed beneath the surface by means of a needle fixed to the end of a wooden rod. If this method is inconvenient, a sinker, such as a piece of lead, may be used. The volume of the sinker should first be found and then the volume of both the solid and sinker by tying them together. The difference between the two volumes gives the volume of the solid.



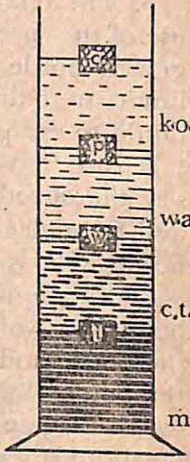
Finding the volume of an irregular solid.

In the case of a substance which is soluble in water it is necessary to use some other liquid in which the solid is insoluble in order to find its volume.

5. The density of a liquid may be found as follows. First weigh an empty vessel, such as a beaker. Then , by means of a pipette, run off 25 c.c. of the liquid into the beaker. Now obtain the weight of the beaker and its contents. By subtraction, calculate the weight of 25 c.c. of the liquid and then calculate the weight of 1 c.c.

6. Obtain equal volumes of the following liquids: mercury, carbon tetrachloride, water and kerosene oil. Pour these liquids into a gas jar in the order given. Now drop into the jar an iron nut, a piece of wood which sinks in water, such as ebony, a lump of paraffin wax and a cork. You will notice that each of these solids floats at different levels in the jar. Try to explain the result.

7. The relative density of a solid may be found by the use of the hydrostatic balance. Suspend the given solid by means of a thread from the hook of the left-hand pan of the balance and obtain its weight. Next place the bridge over the left-hand pan and place a beaker of water on it. Now find the weight of the solid in water taking care that the solid is fully immersed in the water and that it does not touch the sides of the beaker. Care should also be taken that the balance swings freely without touching either beaker or bridge. The apparent loss of weight of the solid can be obtained by subtracting its weight in water from its weight in air. By Archimedes' principle we know that the apparent loss of weight when a body is immersed is equal to the weight of water displaced. Calculate the relative density of the solid.



How to make four different kinds of solids float at different levels in a jar.

c, cork; c.t., carbon tetrachloride; i, iron; k.o., kerosene oil; m, mercury; p, paraffin wax; w, wood; wa., water.

$$\text{Rel. dens. of solid} = \frac{\text{Wt. of solid in air}}{\text{Wt. of solid in air} - \text{Wt. of solid in water}}$$

$$= \frac{\text{Wt. of solid in air}}{\text{Wt. of water displaced}}$$

$$= \frac{\text{Wt. of solid in air}}{\text{Wt. of its own volume of water}}$$

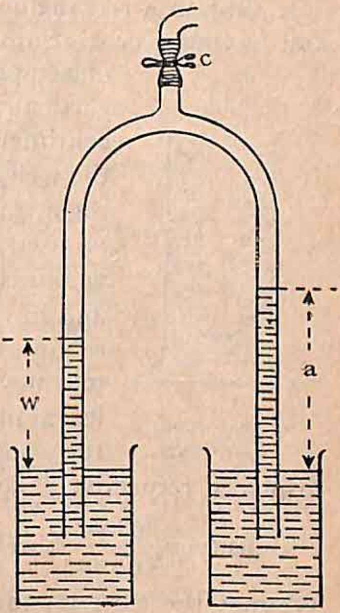
8. The relative density of a liquid may be found by the use of the specific gravity bottle. Take a clean dry specific gravity bottle and weigh it. Fill the bottle with the given liquid up to the brim, insert the stopper and allow the excess liquid to escape through the hole in the stopper. You must take care that no air bubbles remain in the bottle. Carefully dry the outside of the bottle with several folds of a duster and reweigh the bottle with its contents. Do not touch the bottle with your hand as the warmth from your hand will cause the liquid in the bottle to expand and ooze out of the bore. This would give you an inaccurate result. Now empty the bottle and rinse it thoroughly with water and then fill the bottle with water. Wipe the outside of the bottle and weigh it again. In this way the weights of equal volumes of the liquid and of water can be obtained. Calculate the relative density of the liquid.

$$\text{Rel. dens. of liquid} = \left\{ \frac{\begin{array}{c}(\text{Wt. of liquid} + \text{Wt. of empty bottle}) \\ - \text{Wt. of empty bottle}\end{array}}{\begin{array}{c}(\text{Wt. of water} + \text{Wt. of empty bottle}) \\ - \text{Wt. of empty bottle}\end{array}} \right.$$

$$= \frac{\text{Wt. of liquid}}{\text{Wt. of an equal volume of water}}$$

9. The densities of two liquids can be compared without the use of a balance or a specific gravity bottle by the use

of an apparatus known as Hare's apparatus. This consists of an inverted U-tube with a small tube connected at the curve of the U. A length of rubber tubing is fitted to the small tube. Dip the lower ends of the tubes into two beakers, one of which generally contains water while the other contains the liquid whose density is required, say, alcohol. By sucking at the top of the rubber tube draw up the liquids into the tubes till one of the liquids almost reaches the top of its tube. Now close the rubber tube with a pinch clip. Since the pressure of the air above each of the two liquid columns is the same and the pressures above the surfaces of the liquids in the beakers are the same it is evident that the difference in the heights of the two columns is due to their different densities. Measure the height of each column from the surface of the liquid in the beaker to the top of the column. We can now calculate the density of alcohol.



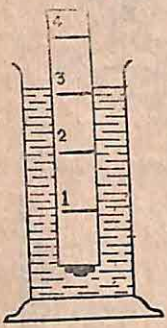
Hare's apparatus.
a, alcohol column; c, clip; w, water column.

$$\frac{\text{Density of alcohol}}{\text{Density of water}}=\frac{\text{Ht. of water column}}{\text{Ht. of alcohol column}}$$

$$\text{Density of alcohol}=\frac{\text{Ht. of water column}}{\text{Ht. of alcohol column}}\times\text{Density of water}$$

At home

1. Obtain a rectangular piece of wood about 5 cm. long and having a cross-section of 1 sq. cm. Fix a metal nut at one end of it so as to ensure that it will float vertically when placed in a liquid. Mark off centimeters along its length beginning from the weighted end including the thickness of the metal nut. This length of wood can now be used as a hydrometer. Note the depth which is immersed when it floats in water and in the liquid whose relative density is required. The relative density of the liquid may now be calculated. From what we have learnt in the text we know that the weight of the wood is equal to the weight of the water displaced respectively. Now from the formula:



A home-made hydrometer.

$$\text{Density}=\frac{\text{Mass}}{\text{Volume}},\ \text{we derive Mass} = \text{Density} \times \text{Volume}$$

We may therefore say that,

Density of water × Volume of water displaced = Density of liquid × Volume of liquid displaced

$$\frac{\text{Density of liquid}}{\text{Density of water}}=\frac{\text{Volume of water displaced}}{\text{Volume of liquid displaced}}$$

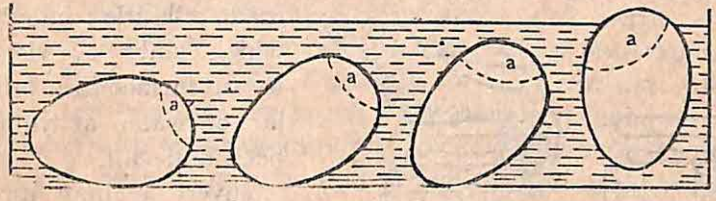
$$\text{Rel. dens. of Liquid} = \frac{\text{Volume of wood immersed in water}}{\text{Volume of wood immersed in liquid}}$$

Since the volume of a rectangular solid = length × breadth × height, and since both length and breadth are the same in each case we may say that

$$\text{Rel. dens. of liquid} = \frac{\text{Height of wood immersed in water}}{\text{Height of wood immersed in liquid}}$$

2. Everybody knows that eggs are tested for freshness

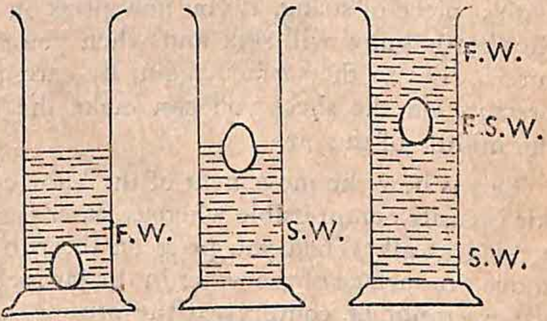
by putting them into a vessel of water. Stale eggs are less dense than water and so float, while fresh eggs being more dense than water sink. In some cases an egg tilts at the bottom of the vessel, the more it tilts away from the bottom the staler it is. The reason behind these facts is interesting.



Testing eggs for freshness.
a, air space.

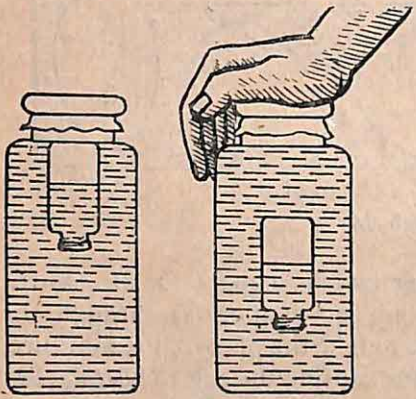
Within the egg, at its larger end, is a space for air. As the days go by, moisture in the egg evaporates through the porous shell and as air enters to take the place of the moisture, the space becomes larger thus causing the egg to become less dense. The next time the egg-vendor sells eggs to your family, help Mother to separate the fresh eggs from the stale ones.

3. Half fill a jar with a strong solution of salt. Take a fresh egg and place it in the solution. You will notice that the egg floats as it is lighter than the weight of an equal volume of salt water. Gently pour some fresh



How to float an egg in the middle of a jar.
F.W., fresh water; S.W., salt water; F.S.W., fresh and salt water.

water into the jar. If you do this carefully, the two liquids will mix only at the middle of the jar. You will notice that the egg neither sinks nor rises to the surface but instead floats half-way up the jar. Can you explain this?

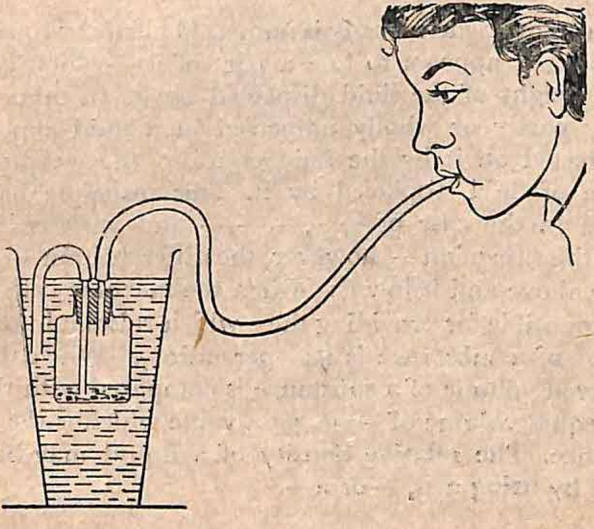

A 'bottle buoy'.

4. You can puzzle your friends by showing them a home-made 'bottle buoy', which sinks or rises to the surface in a tall jar of water at your beck and call.

Invert a small unstoppered bottle and place it in a jar of water allowing just enough water to enter into the bottle so as to bring it nearly to the point of sinking. Cover the mouth of the jar with a thin rubber sheet and tie it firmly to the jar with a piece of string. If you now press on the rubber sheet the 'bottle buoy' will sink and when you remove the pressure it rises to the surface again. By carefully adjusting the pressure on the sheet you can make the buoy hesitate at the middle of the jar.

This is how the movement of the buoy can be explained. Air is easily compressible whereas water can hardly be compressed at all. When you press on the rubber sheet the air above the surface of the water in the jar is compressed. Since water cannot be compressed the pressure is transmitted by the water to the air in the bottle which is thus made to occupy less space. When this happens a very small amount of water enters the bottle and increases its weight making it sink. As the pressure on the rubber sheet is removed the air in the bottle regains its original volume, expels the water that has entered and since the bottle now has its original weight it rises once more to the surface.

5. You can demonstrate quite easily how a submarine is raised and lowered by using a bucket, a glass bottle, glass and rubber tubes, a two-holed stopper and a few nuts and bolts. Put the nuts and bolts into the bottle so that when immersed in water the bottle floats in an upright position and insert the two-holed stopper. Insert a glass tube through one hole of the stopper so that its lower end is near the bottom of the bottle and attach a rubber tube to the upper end of the tube. Insert the second glass tube through the other hole of the stopper so that its lower end is just below the



To show the principle by which a submarine is raised and lowered.

lower surface of the stopper and attach a rubber tube to the upper end of the tube. Now float the bottle in a bucket of water and withdraw some of the air in the bottle by sucking at the end of the second rubber tube as shown. As you do this, water will siphon into the bottle and as more and more water enters, the bottle sinks. When you blow air into the tube, however, the water in the bottle is expelled and the bottle rises.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces : airships, relative density, weight, force, hydrometer, mass, density, aeroplane, ships, balloons, Archimedes' principle, Hare's apparatus, volume, buoys, pressure, water, specific gravity bottle, upthrust, wings, floating docks, submarines.

—states that when a body is immersed partly or completely in a fluid, it appears to lose a part of its—which is equal to the weight of the fluid displaced by it. In other words a body partly or wholly immersed in a fluid experiences an—exerted on it by the fluid equal to the weight of the volume of fluid displaced by it. This principle has been applied in the case of—,—,—,—,— and various kinds of —. In the case of an—, however, the differences in—between the air above and below its—when the machine is in motion are responsible for providing the—which raises it into the air.

The—of a substance is its—per unit—. When the mass of a given volume of a substance is compared with the mass of an equal volume of —we get a value which is the—of the substance. The relative density of a liquid may be determined by using a—, —or a—.

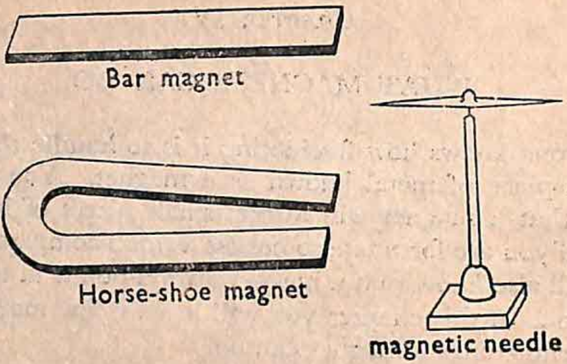
CHAPTER IV

WHAT MAGNETS CAN DO

EVERYONE knows how fascinating it is to handle that mysterious piece of metal known as a magnet. You already know that a magnet will attract small pieces of iron and steel. If you are fortunate to possess a small compass needle, you will also know that a magnet always points in the same direction. In this chapter you will learn a few more of the wonderful things a magnet can do.

Lodestone. Over 2,000 years ago a certain kind of iron ore was found to have the peculiar property of attracting iron and steel and other ores like itself. It was called magnetite after the town of Magnesia in Asia Minor where it was first discovered. It is generally believed that the Chinese were the first to discover that if a piece of magnetite was suspended by a string so that it could turn around easily in a horizontal plane, one end of it always pointed North. Once this property had been discovered, sailors in European countries floated a long thin piece of magnetite on a piece of wood and used it to determine the direction in which they had to sail. It was thus no longer necessary to depend on the positions of the sun and stars for guidance. The fact that magnetite was employed for leading or directing people gave it the name of leading-stone or lodestone.

Natural and Artificial Magnets. The lodestone which has just been mentioned is termed a natural magnet. Steel and iron can be converted into artificial magnets by methods which will be described in the Chapter Activities. When an artificial magnet is shaped in the form of a rectangular bar it is called a bar magnet; when shaped in the form of a horseshoe it is called a horse-shoe magnet and when shaped in



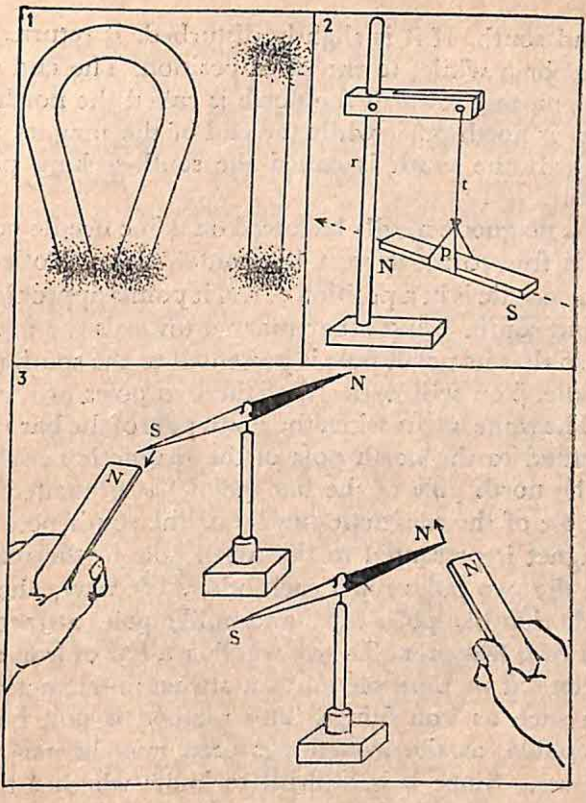
Kinds of magnets.

the form of a needle it is called a magnetic needle. Artificial magnets possess all the properties of a natural magnet but since they are more powerful, find greater use.

Magnetic Substances. These are substances that can be converted into magnets. Iron, cobalt, nickel, and alloys containing these together with other metals are examples of magnetic substances. The first two substances in this list show strong magnetic powers. Magnets attract only magnetic substances.

Properties of a Magnet. If you dip a bar magnet into some iron filings and then withdraw it, you will notice that the filings cling thickly to each end of the magnet, but are not attracted to the middle. The two points of the magnet where the force of attraction appears to be concentrated are called the poles. A horse-shoe magnet is thus more powerful than a bar magnet as it is shaped so that both its poles can be brought to act on an object with equal force at the same time.

Now suspend a bar magnet in a paper sling by a piece of unspun silk. You will see that after some time the magnet comes to rest in a fixed direction which is approximately



To show the properties of a magnet.
N, North pole; S, South pole.

1. *Iron filings adhere to the ends of a magnet.*
2. *A freely suspended magnet takes up a North-South position as shown by the broken arrow.*

p, paper stirrup; r, wooden retort stand; t, fine silk thread.

3. *To show that unlike poles attract whereas like poles repel.*

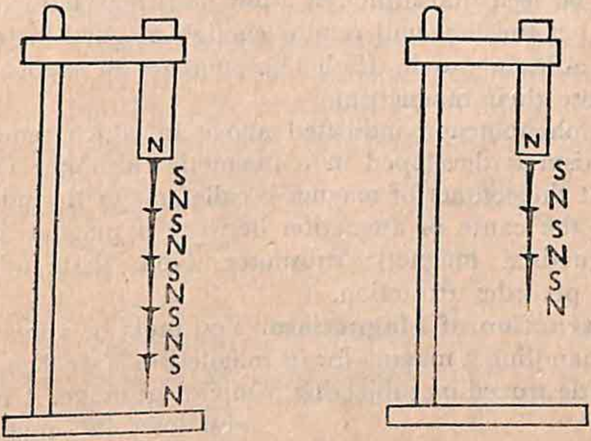
The arrows show the direction in which the magnetic needle moves.

north and south. If it is slightly disturbed, it returns, after swinging for a while, to the same position. The end of the magnet pointing towards the north is called the north-seeking pole or north pole, while the end of the magnet pointing towards the south is called the south-seeking pole or south pole.

Take a magnetic needle balanced on a fine needle point so that it is free to move in a horizontal plane. Notice that when the needle is in a position of rest it points approximately north and south. Bring a bar magnet towards the magnetic needle so that its north pole is presented to the south pole of the needle. You will notice that the two poles attract each other. The same is true when the south pole of the bar magnet is presented to the north pole of the magnetic needle. But when the north pole of the bar magnet is presented to the north pole of the magnetic needle or the south pole of the bar magnet is presented to the south pole of the magnetic needle, the two poles repel each other. We may, therefore, conclude that like poles repel and unlike poles attract.

Test of a Magnet. To test whether a bar of iron or steel is magnetised we must see if it can attract unmagnetised bits of iron such as iron filings. This method is not, however, very reliable, as the iron filings used may be magnetised themselves. Since it is difficult to know whether the iron filings are magnetised we must resort to an alternative method. Present one end of the given bar to the north pole of a magnetic needle. If both ends attract one another it still does not necessarily follow that the bar is a magnet, as attraction always occurs between an unmagnetised piece of iron or steel and a magnet. It will be necessary, therefore, to present the other end of the bar to the north pole of the magnetic needle. If repulsion takes place it surely means that the bar under examination is a magnetised one. Repulsion, therefore, is the surest test in distinguishing a magnetised piece of iron or steel from an unmagnetised one and also in determining the polarity of a magnet.

Magnetic Induction. Fix a bar magnet in the clamp of a wooden retort stand with its north pole pointing away from the clamp. Bring an unmagnetised iron nail to the pole of the magnet. The nail is attracted to the magnet. If another nail is brought close to the first nail it is attracted and adheres to the first nail. In this way you will find that a number of nails can be made to hang from the magnet, the exact number of nails depending on the strength of the magnet. Each nail attracts the one below it because, while under the influence of the magnet, it also becomes a magnet and has the power of attracting a magnetic substance.



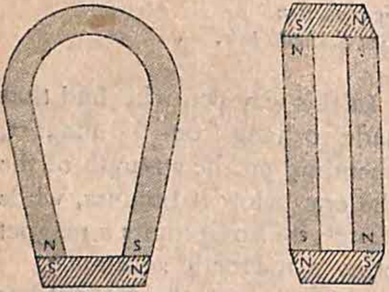
Magnetic induction.
N, North pole; S, South pole.

The near end of the nail in contact with the magnet has opposite polarity to the pole with which it is in contact, while the lower end of the nail has the same polarity as the pole of the magnet to which the nail is attached. The polarity of the nail can be tested by bringing a magnetic needle near the bottom end of the nail. The distribution of north and south poles throughout the chain of nails is as indicated in the figure.

Continue the experiment further by gently disconnecting the first nail from the magnet and holding it close to the magnet, though not in contact with it, as in the second figure. It will be seen that although a few nails may fall from the chain, yet the first nail retains enough magnetism to keep others adhering to it. If the bar magnet is removed, the nails lose their magnetism.

The phenomenon indicated above in which temporary magnetism is developed in a magnetic substance with or without the contact of magnet is called magnetic induction and is the cause of attraction between a magnet and an unmagnetised magnetic substance. Note that induction always precedes attraction.

Destruction of Magnetism. You must be very careful while handling a magnet for its magnetism is weakened and finally destroyed by subjecting it to violent usage. A magnet also loses its magnetism completely if it is heated until it is red-hot.



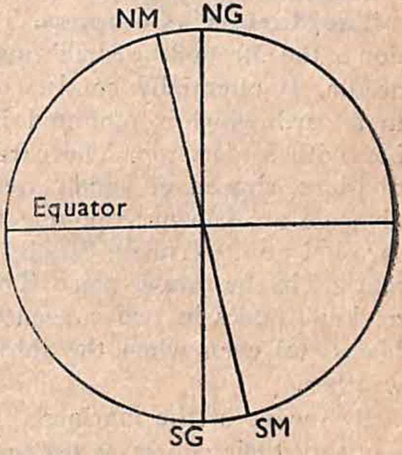
Keepers.
N, North pole; S, South pole.

Keepers. These are little pieces of soft iron used as an aid to the retention of magnetic strength. After use, a pair of bar magnets are arranged with their poles in opposite directions and a piece of soft iron placed across each end. When a horse-shoe magnet is stored away after use, a single keeper is placed across its ends.

When the keeper is in position it becomes a magnet by induction so that each pole of the magnet is faced by an unlike pole of the keeper and because of the power of attraction between unlike poles the magnetic strength of each magnet is less likely to be dissipated.

The Earth's Magnetism. Perhaps you have wondered why a suspended magnet should always set itself in a fixed direction. Scientists experimenting with magnets many centuries ago also found this a difficult problem until they concluded that the earth must itself act as a huge magnet. Subsequent experiments and expeditions proved their theories to be correct.

The earth behaves as though there is a huge magnet placed inside it whose axis is slightly inclined to the geographical axis of the earth at an angle of about 17° and whose North and South poles are close to the geographical North and South poles. Although it is very unlikely that there is a bar of magnetic substance actually contained in the earth, yet the North and South magnetic poles have been explored and located. The North Magnetic Pole has been located at a point 1,500 miles away from the geographical North pole.



The poles of the earth.
N.G., North Geographical pole;
S.G., South Geographical pole;
N.M., North Magnetic pole;
S.M., South Magnetic pole.

It should be noted that the direction of this supposed magnet or its equivalent changes slightly from year to year.

While a magnetic needle placed anywhere on the earth's surface is influenced by the magnetic poles of the earth yet at the poles themselves the magnetic needle is useless and points in any direction.

Since unlike poles attract and like poles repel you may become confused as to why the so-called North pole of a magnet points to the North magnetic pole of the earth. This is a mere convention by which we call a North-seeking pole a North Pole and a South-seeking pole a South Pole.

Since the magnetic force exerted by the earth is very weak, any magnet or magnetic substance can easily displace a magnetic needle out of its North-South direction.

The Mariner's Compass. This instrument is an application of the effect of the earth's magnetic action on a magnetic needle. It essentially consists of a magnetic needle fixed to a card which is mounted inside a cylindrical copper box with a glass top. The card is divided into thirty-two divisions, sixteen of which are shown in the figure. The divisions are known as points of the compass, and the four cardinal points (North, South, East and West) are clearly marked in the proper place. The compass box is supported on knife edges in two concentric rings so that it remains horizontal even when the ship rolls and tosses in stormy weather.

By means of the mariner's compass, sailors are able to navigate their course across the sea.

CHAPTER ACTIVITIES

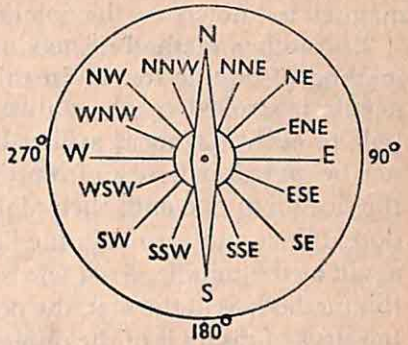
Outdoors

1. Many objects made of iron and steel have been changed into magnets by the magnetism of the earth. Secure a pocket

compass and use it to find out whether the common iron and steel objects around your home have been magnetised. Remember to test each end of the object with your compass to see if it is a magnetic pole.

2. If you have an opportunity, visit an ocean-going vessel and ask to be shown the mariner's compass. Find out how it is used.

3. Purchase a pocket compass. You will find it useful during your rambles.



A simple compass card showing 16 points of the compass. Do you know what the letters stand for?

For your wall newspaper

You will read on page 93 how the magnetic field of a magnet can be explored with the help of a pocket compass. Pin your results to your board.

Note-book exercise

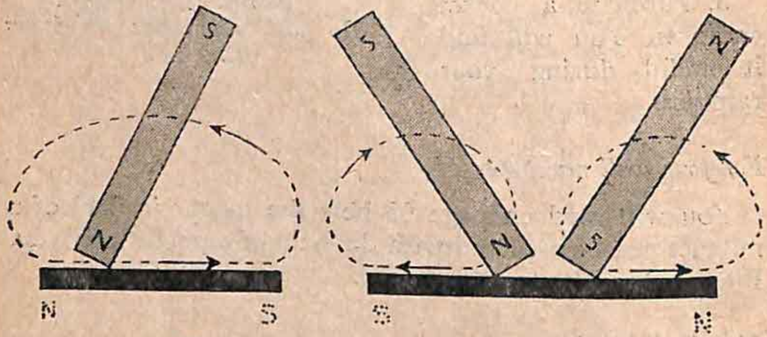
Write a summary of this chapter.

Laboratory work

1. Magnetise a piece of steel such as a knitting needle by stroking it a number of times in one direction with one pole of a powerful bar magnet. After the knitting needle has been magnetised, test each end of it with a magnetic needle to determine its polarity. You will notice that the end of the needle where the stroking magnet left off is of opposite

polarity to the stroking pole. This method of making a magnet is known as the method of single touch.

2. Another method of making a magnet is known as the method of double touch. In this method the unmagnetised needle is stroked by the unlike poles of two magnets. The pole of each magnet is at first brought to the middle of the needle and drawn away from the other, from the middle of the needle to one end, then along the path as shown by the dotted lines and arrows in the figure until the two meet once again at the middle, from where the stroking is repeated. In this method, as in the first, the pole produced at the end where the stroke finishes is of the opposite kind to the stroking pole.



Two methods of making a magnet.
Left: single touch. Right: double touch.
The arrows show the directions in which the bar magnets move.
N, North pole; S, South pole.

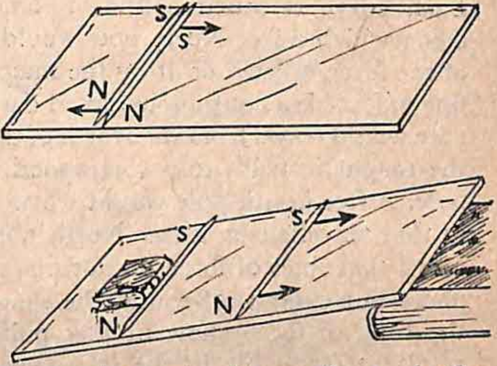
3. The effect of the earth's magnetism can be used to convert a rod of iron or steel into a magnet. Hold the rod so that it points to the magnetic North and incline it to an angle about 30° from the horizontal. Continuously hammer the rod along its length with a wooden mallet for a few minutes. Then test the rod with a compass to see if it has

become a magnet. If you wish to demagnetise the rod, tap it when held in an east-west direction.

4. Soft iron is more readily magnetised than steel, but its power of retaining magnetism after the magnetising force has been removed is smaller than that of steel. Devise methods of testing these statements in the laboratory.

5. Magnetise two knitting needles. Place them side by side with their North poles together on a slide of glass. Notice how they roll apart due to the fact that like poles repel each other.

Repeat the experiment with the glass slightly tilted and one magnet supported in the middle. Notice how the second magnet rolls uphill showing that magnetism is a force that can be made to do work.



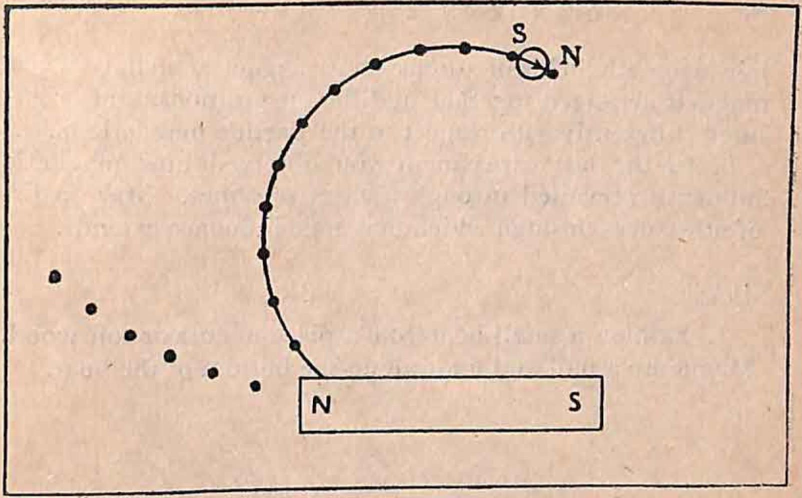
Two round magnets roll away from each other when their like poles are placed in contact.

6. To explore the magnetic field of a magnet, i.e. the space surrounding the magnet in which its influence is exerted, you will need a bar magnet and a small pocket compass. Place the magnet on a sheet of white paper and bring the compass near its North pole. The poles of the compass needle are now acted on by the poles of the bar magnet. One pole of the bar magnet attracts the unlike pole of the needle while the other pole of the magnet repels the like pole of the needle, the pole nearest the needle having the greater force. As a result of these forces the needle takes up a position as shown in the diagram.

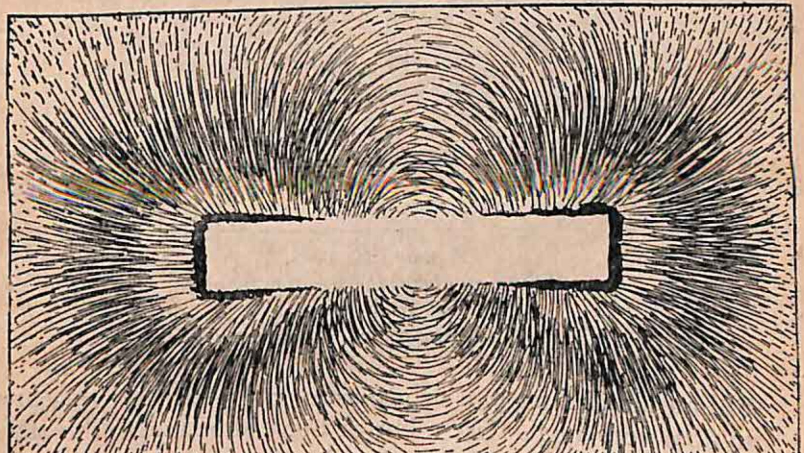
Make a mark with a pencil exactly under the North pole of the needle. Now move the compass until its South pole is over the dot and make another dot under the North pole of the needle. Repeat the process until the compass reaches the other pole of the magnet. Draw the outline of the magnet and then draw a smooth curve so as to connect all the dots. Plot a series of such curves by starting each time from different points along the length of the magnet. Each curve is called a line of force and shows the path along which a free North pole would move under the action of the force exerted on it by the magnet. Furthermore, each line of force is a continuous closed curve, that is, a free North pole would travel from the North of the magnet, then through the magnetic field, to a corresponding point on the South pole. A free South pole would travel in a direction opposite to that travelled by a free North pole. It must be remembered that lines of force do not merely exist in a horizontal plane but extend all round the magnet as well. In reality the lines of force show at any point the direction of the resultant force due to the combined action of the magnet and the Earth's magnetic field; however, the latter is small compared with that of the magnet at points close to the magnet.

7. Place a bar magnet on the table and place a sheet of white cardboard over it. Sprinkle iron filings evenly on the cardboard. Tap the cardboard gently until the filings take up a definite pattern. Compare this pattern of a magnetic field with that obtained by the use of a compass needle. You will notice that the patterns are alike. As each filing falls on the cardboard it becomes a magnet by induction. When the cardboard is tapped each filing behaves like a tiny compass needle and takes up a position along a line of force.

A sheet of cardboard and iron filings will help you to ob-



How to draw lines of force with a compass.
N, North Pole; S, South Pole.



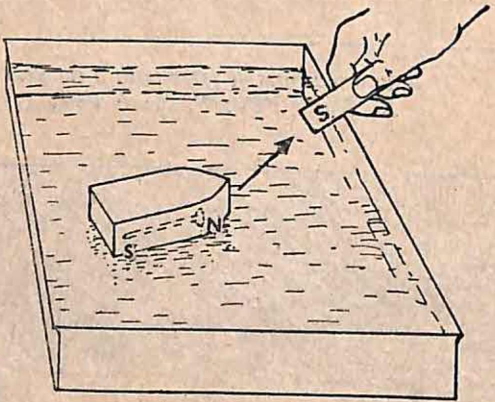
The lines of force around a bar magnet as shown by iron filings.

tain magnetic fields of a horse-shoe magnet as well as of bar magnets arranged together in different positions, and orientated differently with respect to the Earth's magnetic field.

8. In the last experiment you observed how magnetic influence prevailed through a sheet of paper. Make a list of substances through which magnetic influence extends.

At home

1. Fashion a small boat from a piece of cork or soft wood. Magnetise a nail and fix it along the bottom of the boat.

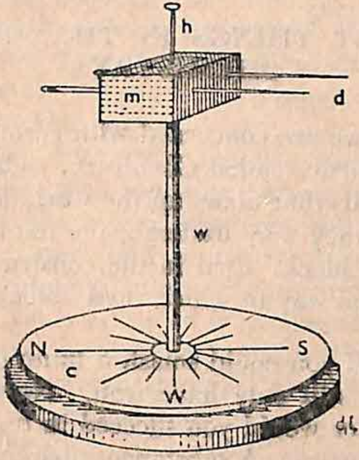


A magnetic boat.
The arrow shows the direction in which the boat moves.
N, North pole; S, South pole.

Fill an aluminium pan or a plastic tray with enough water to float your boat. Use a bar or horse-shoe magnet to steer your boat from 'shore' to 'shore'.

2. Use the figure given on page 91 to make your own compass card. Mount the card on a large wooden disc.

Magnetise two large darning needles. Push the needles through the match-striking sides of a match-box so that their



Make this compass.
c, compass card; d, magnetised darning needles; di., wooden disc; h, hat pin; m, match-box; w, wooden support; N, north; S, south; W, west. (The bead on which the match-box rests cannot be seen in the picture.)

North poles point in the same direction. Mount the match-box at the centre of the card with the help of a hatpin, a piece of wood and a bead.

CHAPTER V

THE FIRST THINGS IN THE STUDY OF CHEMISTRY

IN this chapter we are concerned with certain fundamental concepts of a science called Chemistry. This science deals with the materials that make up the world and the changes in composition they may undergo, the nature and number of the 'building blocks' used in the construction of various materials and the way in which these 'blocks' interact with each other.

Elements. If you could smash a lump of iron into tiny bits you would still only have iron. No other substance would appear nor would you succeed in breaking iron into anything else but iron. A substance, such as iron, which no one has yet been able to break up into two or more different kinds of substances is called an element.

After performing innumerable experiments scientists have come to the conclusion that there are at least 100 different elements that are known to exist on and around the earth. These elements combine with one another in various ways, under certain conditions, to form the things we see around us. Just as there are thousands of words made from only a few letters, so also there are thousands of things made from only a few elements. Moreover, just as there are some letters, such as q, x, y, and z which are not used so often as the others, so also there are some elements which are rarely found in combination with other elements and which are difficult to find, lurking as they do, in the far corners of the earth.

Some elements in their natural state are gaseous, e.g. Oxygen, Nitrogen, Hydrogen, Chlorine and so on. Some, like Mercury and Bromine, are liquids. A great many are solids. For the sake of convenience, chemists divide all elements into two great classes — metals and non-metals. Aluminium, Copper, Iron, Lead, and Zinc are a few of the metallic elements we meet with in our daily life. Carbon, Iodine, Phosphorus, Silicon and Sulphur are examples of common non-metals.

Now let us consider two common elements, iron and sulphur, and find out something about their properties. Place some iron filings and powdered roll sulphur side by side. You will at once note that iron is lustrous and has a greyish colour, whereas sulphur is not lustrous and has a yellow colour. Iron is attracted by a magnet but sulphur is not attracted. Iron is insoluble in* carbon disulphide, whereas sulphur is soluble. Furthermore, if a piece of iron is put into a test tube containing dilute hydrochloric or sulphuric acid, a gas will be given off. This does not happen in the case of sulphur. These facts show that each of the two elements have their own separate and distinctive properties by which they can be identified.

Mixtures and Compounds. Take small quantities of iron and sulphur and mix them together. Although the colour of the mixture is somewhat different from the colour of the original substances in it, yet when viewed through a powerful magnifying glass the particles of iron can be easily distinguished from the particles of sulphur. If you run a magnet through the mixture, the iron particles in the mixture are attracted. In fact, a magnet can be used to separate the iron from the sulphur. When the mixture is shaken with carbon disulphide and filtered, it is seen that the sulphur has dissolved in the carbon disulphide and can thereafter be recovered by evaporation. Finally, when the mixture is

*Carbon disulphide is highly inflammable and must not be used near a flame.

treated with dilute hydrochloric or sulphuric acid, a gas is given off from the iron as before. We may conclude then, that even though the mixture looks like a separate substance, the elements of which it is composed retain their individual properties. Whether the mixture was made up of a small quantity of sulphur and a large amount of iron, or vice versa, makes no difference, for when tested as above you will obtain the same results.

Now we all know that letters of the alphabet cannot be joined together in just any way to make a word, but must be combined in a certain definite way. Elements must also be combined in certain definite ways to make substances called compounds.

Take small quantities of iron and sulphur and mix them together in a test tube. Warm the tube over a flame. Soon a glow appears. You may now remove the tube from the flame. The glow gradually spreads through the contents of the tube. The heat produced is so great that the glass of the test tube melts or cracks. Obviously this heat has not come from the flame but from the chemical action taking place inside the test tube.

Break the test tube and inspect its contents. You will not be able to tell the iron from the sulphur even with the help of a magnifying glass, nor will you be able to separate the iron from the sulphur with the aid of a magnet. The substance is quite insoluble in carbon disulphide. When acid is added to the substance a gas is given off. Is it the same gas as before? Its smell will convince you that it is not.

The elements of which the new substance, called iron sulphide, is composed seem to have entirely disappeared provided certain definite proportions of the two elements were taken. Not a trace of them can be seen nor does the substance have the properties of its constituents. It has an appearance and properties of its own. The two elements have combined together to make a new substance which is called a compound.

An interesting fact about the compound we have just made is that the elements are combined together in definite proportions by weight.

A metal called Sodium combines with a poisonous gas called Chlorine to make a compound which we eat every day, called common salt. Two gases, Hydrogen and Oxygen, combine together to form a compound without which life is not possible, a compound which is a liquid called water.

Physical and Chemical Changes. If a bar of iron is heated over a strong flame it expands and becomes red-hot. But in spite of these changes the iron bar does not become some other substance. On allowing the iron bar to cool, it regains its original length and colour. The change which the iron bar underwent when heated is an example of a physical change.

When we combined iron with sulphur to form iron sulphide, the two elements were converted into an entirely new substance, during the formation of which heat was given off. Also, it was not possible to convert the iron sulphide back to the original substances. Such a change, as undergone by the iron and sulphur, is a chemical change.

Atoms and Molecules. If a piece of an element were divided and sub-divided into such tiny bits that they could not be further divided, that smallest particle of the element would be an atom. Atoms are, so to speak, the 'building blocks' with which all elements are built up. Although nobody has ever seen an atom since it is so tiny, yet scientists believe that all atoms of the same element are essentially alike and differ from those of any other element. Moreover, atoms of one kind cannot ordinarily be changed into any other kind.

Single atoms are not very common in nature, but usually combine together to form a group called a molecule. Thus atoms of the same element may combine together to form a molecule. In the case of gases such as oxygen, nitrogen and hydrogen, the atoms of these elements are combined together in groups of two. Atoms of different elements may also combine with one another to form a molecule of a compound. For example, a molecule of common salt is composed of one atom of sodium and one of chlorine.

Molecules, like atoms, are so small that they cannot be seen even with the most powerful microscopes. With the invention of the electron microscope, however, a large molecule such as that of protein which is composed of thousands of atoms, can now be seen.

It must be remembered that an atom is the smallest part of an element that can take part in a chemical reaction, whereas a molecule is made up of atoms and is the smallest part of an element or compound which is capable of an independent existence and possesses the chemical properties of that element or compound.

Chemical Symbols. The name of every element is abbreviated by a symbol which is usually the initial letter of its English or Latin name. The symbol represents one atom of the element. Thus the symbol H represents one atom of hydrogen. O represents one atom of oxygen. Since the names of several elements begin with the same letter, a second letter is also used. Thus Calcium is represented by Ca, Chlorine by Cl, Chromium by Cr and Copper (known by its Latin name of Cuprum) is represented by Cu. The following table gives the symbols of most of the common elements. In the table the Latin names of elements are given in parenthesis.

Name of Element	*Symbol*	*Name of Element*	*Symbol*
Aluminium	Al	Mercury (Hydrargyrum)	Hg
Calcium	Ca	Nickel	Ni
Carbon	C	Nitrogen	N
Chlorine	Cl	Oxygen	O
Chromium	Cr	Phosphorus	P
Copper (Cuprum)	Cu	Potassium (Kalium)	K
Gold (Aurum)	Au	Silicon	Si
Helium	He	Silver (Argentum)	Ag
Hydrogen	H	Sodium (Natrium)	Na
Iodine	I	Sulphur	S
Lead (Plumbum)	Pb	Uranium	U
Magnesium	Mg	Zinc	Zn
Manganese	Mn		

Formulae. In chemistry, formulae are combinations of symbols and numbers which indicate the atoms of elements which are united together to form a molecule and also the number of atoms of each element that have gone into the union.

The kind of atom is represented by its symbol while the small figure placed after the symbol indicates the number of atoms joined together to form a molecule. Thus, H_2 represents a molecule of hydrogen in which two atoms are joined together. A large figure placed before the symbol of an element indicates that the atoms of the element are not joined together to constitute the molecule. Thus 2H represents two atoms of hydrogen apart from each other. $2H_2$ indicates two molecules of hydrogen grouped together as a pair, each of which contains a pair of atoms, making a total of four atoms. The large numeral thus multiplies the whole of the formula.

Compounds are also represented by symbols in a way which is similar to elements. Thus, H_2O represents a molecule of water. It is clear from what has already been said that this formula indicates that a water molecule contains two atoms of hydrogen and only one of oxygen.

Sometimes several atoms are enclosed in brackets with a small number placed on the outside of the bracket as in $Zn(NO_3)_2$. This means that two NO_3 groups are combined with a single Zn atom. The small numeral outside the bracket multiplies all the atoms within the bracket, that is, two atoms of nitrogen, six of oxygen and one atom of zinc, making a total of nine atoms, have combined together to form a single molecule of a compound called zinc nitrate.

It must be clearly understood that a formula represents a chemical combination of the elements involved as denoted by the close proximity of the symbols and that the elements as given by the formula are linked together in very definite proportions. Moreover, the formula of an element or compound is the symbolic representation of a single molecule of that element or compound.

Chemical Equations. Perhaps the most useful thing about symbols and formulae is that they serve the chemist as a simple shorthand system by means of which he can refer to chemical combinations briefly and in a condensed fashion. In a chemical equation the formulae of the reacting substances are written first and then followed by an arrow which points to the formulae of the products. The arrow indicates the direction in which the change takes place.

The substances formed have different properties from those substances at the commencement. The atoms which compose the new substances, however, were present in the original substances, that is, the number of atoms before and after the reaction remains the same.

When substances react chemically with one another, their atoms are torn out of their old combinations and regrouped together in new combinations. During the reaction new atoms are not created nor are they destroyed or split apart.

In the equation:

$$NaOH + HCl \longrightarrow NaCl + H_2O,$$

one sodium atom, one oxygen atom and one hydrogen atom were originally combined together to form a molecule of sodium hydroxide, as were an atom of hydrogen and an atom of chlorine to form a molecule of hydrochloric acid. These molecules were broken up during the chemical reaction and new molecules formed from the parts. In the products of the reaction, the sodium atom joined itself to the chlorine atom to form a molecule of sodium chloride, while two atoms of hydrogen joined themselves to the atom of oxygen to form a molecule of water.

By means of a chemical equation, the chemist can trace the atoms through a reaction from their original combination to their new combinations. It is important to note, however, the limitations of an equation. It is merely a record of something that has been observed, it does not give any information of the conditions under which the reaction takes place or whether the products are in the form of gases, liquids or solids.

CHAPTER ACTIVITIES

Outdoors

1. Make a collection of elements and compounds in the solid state. Keep each substance separate in match-box compartments.
2. Take note of the physical and chemical changes that occur around you.

For your wall newspaper

Illustrate this chapter with suitable sketches.

Note-book exercises

1. Make lists of elements, compounds and mixtures that are in everyday use in your home.

2. Tabulate your observations of the experiments suggested in the chapter as follows:

Test	*Iron*	*Sulphur*	*Mixture of Iron and Sulphur*	*Iron Sulphide*
Appearance				
Action of magnet				
Action of dilute acid				
Action of Carbon disulphide				

3. Identify as physical or chemical, the changes that occur in each of the following:

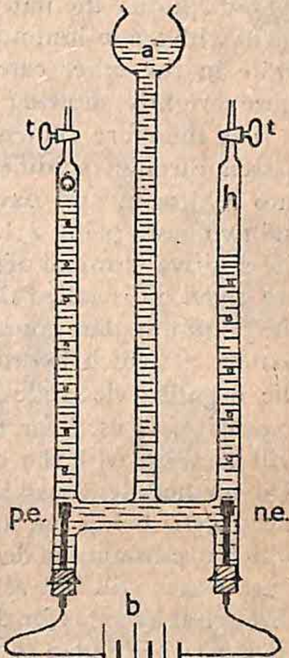
(*a*) The rusting of an iron bar.
(*b*) The planing of a wooden board.
(*c*) The stretching of a piece of elastic.
(*d*) The burning of a candle.
(*e*) The beating of an egg.
(*f*) The adding of water to quicklime.
(*g*) The crushing of a rock.
(*h*) The striking of a match.
(*i*) The exploding of a cracker.
(*j*) The melting of wax.
(*k*) The freezing of a pond.
(*l*) The development of a photographic plate.

(*m*) The breaking of a tumbler.

(*n*) The gluing of two sticks together.

(*o*) The sharpening of a pencil.

4. Consult books in your science library and collect enough material to write a brief biography of Cavendish.



A voltameter.

a, *acidulated water*; *b*, *battery*; *h*, *hydrogen* (*2 volumes*); *n.e.*, *negative electrode* (*cathode*); *n.t.*, *negative terminal*; *o*, *oxygen* (*1 volume*); *p.e.*, *positive electrode* (*anode*); *p.t.*, *positive terminal*; *t*, *taps*.

Laboratory work

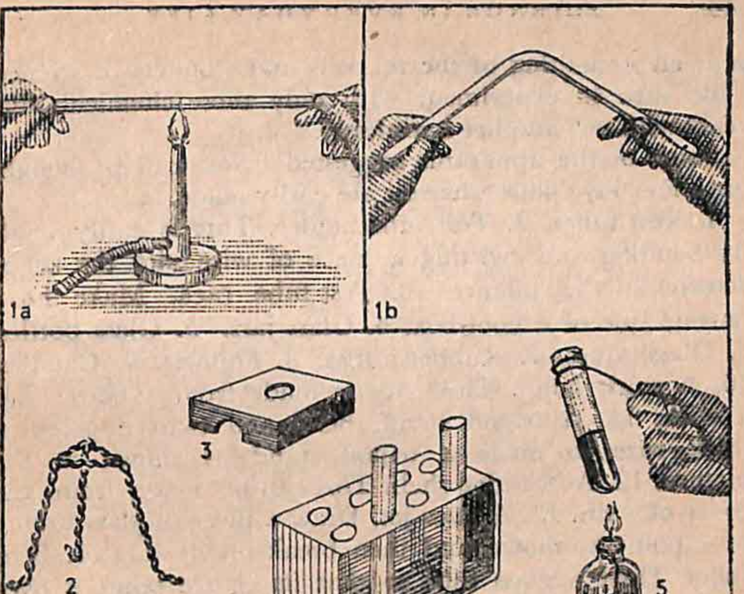
That water is a compound composed of two volumes of hydrogen united with one volume of oxygen can be demonstrated in the laboratory by the use of an apparatus called the Voltameter. The apparatus consists of a U-tube connected to a central reservoir tube. Each limb of the U-tube has a tap fitted at the top. Inside each limb is a small plate of platinum which is connected by means of a wire to the terminals of a battery.

At the beginning of the demonstration, the taps are opened and the apparatus is filled to the level of the taps with water to which a little sulphuric acid has been added. The taps are then closed and a current of electricity passed through the acidified water. You will now notice that bubbles of gas are given off from the platinum plates and begin to collect at the top of each side tube. Notice also, that twice as much gas collects in one arm as in the other. If the taps are now opened and the gas allowed to escape, we can prove by means of a lighted splinter the nature of each gas. In one case, the gas burns with a non-luminous flame showing that it is hydrogen, while in the other case, the gas makes the splinter burn more brightly showing that it is oxygen.

It is therefore evident that when an electric current is passed through acidified water, the water is decomposed into hydrogen and oxygen, the proportion by volume of the two gases being 2:1. The platinum plate connected to the positive terminal of the battery at which oxygen bubbles are given off is called the positive electrode or anode, while the platinum plate connected to the negative terminal of the battery at which hydrogen bubbles are given off is called the negative electrode or cathode. Platinum, though very expensive, is used for this experiment as any other metal will combine with the oxygen given off to form an oxide. The method described here is called the electrolysis of water, electrolysis being the name given to a process by means of which a substance is decomposed by a current of electricity. Pure water will not allow a current of electricity to pass through it and it is for this reason that a few drops of sulphuric acid were added to the water. The amount of acid used, however, remains unchanged throughout the process.

At home

You can have good fun and spend many magic hours with a chemistry set. It is not expensive to make, for many of the materials you need are to be found in the kitchen or in the medicine cabinet in your home. By using your chemistry set cleverly and well you can perform many of the experiments described in this book, and thereby discover for



Home-made apparatus.

1. (*a and b*) *How to bend a glass tube.* 2. *Tripod stand.* 3. *Bee-hive shelf.* 4. *Test-tube rack.* 5. *Spirit lamp and test-tube holder.* 6. (*a and b*) *How to make a glass jet.*

yourself something of the marvels and wonders of science.

Be sure to experiment with only those chemicals that react with one another harmlessly.

Some of the apparatus suggested below can be bought for a few naye paise, the rest are easily made.

1. Test tubes. 2. Test tube holder. This is easily made by bending and twisting a piece of wire into the shape shown in the picture. 3. Test tube rack. Make holes on one side of a boot-box. 4. Glass jars. 5. Glass bottles. 6. Glass tubes. 7. Rubber tubes. 8. Funnels. 9. Candles. 10. A spirit lamp. This can be made from a bottle and a wick. 11. A tripod stand. Bend and twist a piece of thick wire to make a tripod stand as shown in the picture. 12. A bee-hive shelf. This can be made from the cover of a tin. 13. A glass jet. Draw a piece of glass tubing to a point as shown and then break off its tip. 14. Bent tubes. Hold a glass tube so that its centre point is over a bunsen flame. When the glass softens, bend the tube to the required angle.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces : mixture, element, equation, molecule, usually, physical, symbol, atom, properties, water, do not, shorthand, formula, reaction, definite, air, heat, compound, chemical, symbolic, constituents, own, combination, reversed, varying.

An—is a substance which no one has yet succeeded in breaking up into two or more different kinds of substances. Every element has its own distinctive—. The constituents in a mixture are mixed in—proportions, but in a compound the constituents are combined in—proportions. The constituents of a—can be separated by mechanical means but this cannot be done in the case of a—. A mixture has the properties and nature of its—. A compound, however, has its—distinctive properties and nature. Heat changes—always occur when a mixture is made. During the formation of a compound, however, heat changes—occur.—is an example of a mixture. —is an example of a compound.

When a substance undergoes a—change it retains its distinctive properties. The change can be—by reversing the conditions causing the change. When a substance undergoes a—change it is converted into another substance. During such a change—is usually either taken in or given out.

The smallest part of an element that can take part in a chemical—is called an—. The smallest part of an element or compound capable of an independent existence and possessing the chemical properties of that element or compound is a—. A chemical—is given to every element and represents one atom of that element. A chemical—is the—representation of a single molecule of an element or compound and represents the chemical—of that element or compound. A chemical—is a simple—way by which a chemical change can be recorded.

CHAPTER VI

OXYGEN

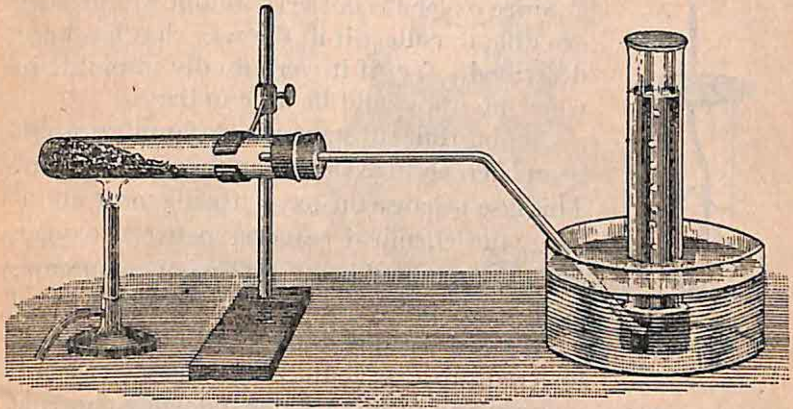
OXYGEN is the most widely distributed of all the elements, forming about one-half of our immediate environment. You have already learnt that air is a mixture of gases and that one-fifth of its volume is oxygen. Almost 90 per cent by weight of water and about 50 per cent by weight of the earth's crust is oxygen held in chemical combination with other elements; it also forms a considerable part of the body structure of animals and plants.

Without this gas all living things would suffocate and die. It is also necessary for burning, rusting and decay. Since it plays an important role in industry and in medicine it is manufactured on a large scale.

Preparation of Oxygen. In the laboratory, oxygen is prepared by heating substances which are rich in oxygen. A crystalline substance called potassium chlorate contains a large quantity of oxygen, but it only gives up its oxygen when heated to a high temperature. If, however, we mix it with a black powder called manganese dioxide we can get oxygen from it more easily and at a lowered temperature. After heating, the potassium chlorate having given up its oxygen, is changed to potassium chloride, but the manganese dioxide remains unchanged. A substance such as manganese dioxide, which by its mere presence hastens the rate of reaction, is called a catalytic agent.

Mix some potassium chlorate with one-quarter of its weight of manganese dioxide and put the mixture in a hard glass test tube. Support the test tube in a horizontal position between the clamps of a retort stand. Fit a one-holed stopper to the test tube. Pass one end of delivery tube through the stopper and let the other end dip into a large trough three-fourths full of water. Place a beehive-shelf over this end to support the gas jar in which the gas is to be collected.

Gently heat the test tube. You will at once notice bubbles of gas rising through the water in the trough. These first few bubbles of gas contain mostly air which was in the test tube and delivery tube. Allow these bubbles to escape. When a steady flow of bubbles comes from the delivery tube, make arrangements for collecting the gas in the following manner.



Arrangement for collecting oxygen by the displacement of water.

Fill several gas jars with water and cover each with a greased glass plate. Now take one of the jars, invert it and lower it carefully into the trough of water. Put it over the top hole of the beehive-shelf and remove the glass plate. The gas rises into the jar and soon displaces the water in it.

The moment the jar is full of gas, slide a glass plate over its mouth and lift it out of the water. Turn the jar right way up and place it, still covered, on a table.

Collect several jars of oxygen in this way. This method of collecting a gas is known as the displacement of water method.

At the end of the experiment, raise the delivery tube out of the water in the trough before you turn the bunsen burner off. If you extinguish the burner and let the apparatus stand as it is, water will rush into the test tube and crack it.

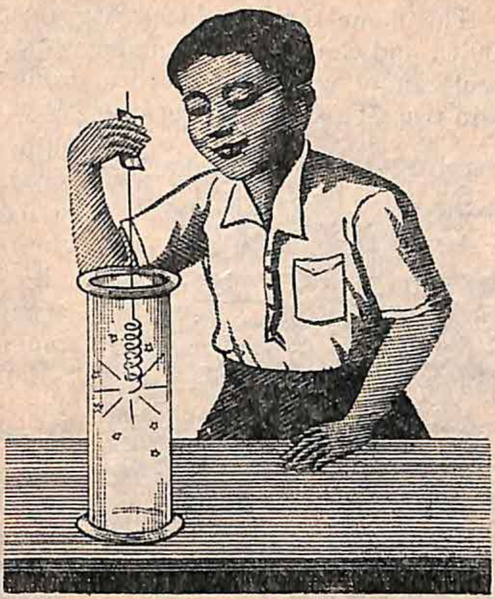
Properties of Oxygen. Oxygen is a colourless gas with no taste or smell. Hence, we are unable to distinguish it from the other gases contained in the air.

Since oxygen is not very soluble in water we are able to collect it in the way that has been described. Yet if it were totally insoluble in water no fish would be able to live.

Combustible substances burn far more rapidly and fiercely in oxygen than they would in air. This is so because the oxygen being more abundant, the chemical reaction between oxygen and the combustible substances is more intense. A glowing splinter of wood thrust into a jar of oxygen bursts into flame. A burning candle lowered into a jar containing the gas burns with a larger and brighter flame. Glowing charcoal taken with a pair of tongs and held in the gas burns brilliantly giving off sparks. Burning sulphur taken in a metal spoon, called a deflagrating spoon, and plunged into the gas burns more brightly. Even iron burns in oxygen.

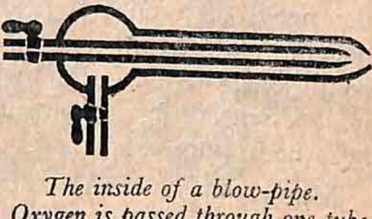
Sulphur burns brightly in oxygen.

Take a piece of thin iron wire and make one end into a little spring. Heat the spring in a bunsen flame until it is red-hot and then dip it into a bowl containing sulphur. The sulphur sticks to the iron spring and burns. Now lower the spring into a jar of oxygen, and watch the fireworks effect produced as the iron burns.



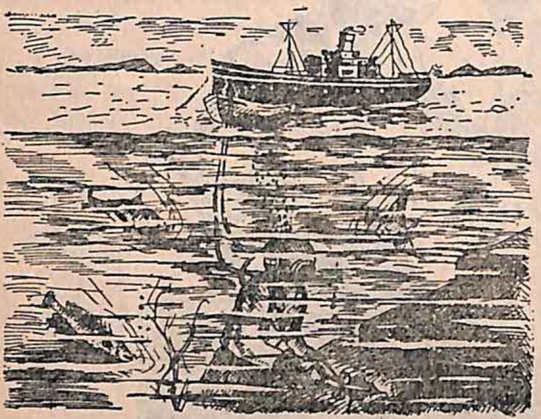
Iron burns in oxygen.

Uses of Oxygen. The fact that substances burn rapidly and fiercely in oxygen with a high temperature, is put to use in the cutting and welding of certain metals such as iron. The instrument used for such a purpose is called a blow-pipe. A gas called acetylene is passed through one of the side pipes of the instrument. Oxygen is supplied through the second pipe and on combining with the acetylene gives a very



The inside of a blow-pipe. Oxygen is passed through one tube while acetylene is passed through the other.

hot flame. The flame thus produced has a temperature of over 3,000°C. and can burn even under water. Sheets of iron and steel cannot withstand the heat from this flame and are cut in two. If a ship carrying valuable cargo suffers shipwreck and sinks, divers are sent down into the sea. With their oxy-acetylene blow-pipes they cut a hole through the iron sides of the ship, enter within and recover the cargo.


Cutting through the sides of a ship.

The oxyacetylene flame is also used to join two pieces of iron. The terrific heat of the flame melts the ends, which when softened stick together firmly. This process is called welding.

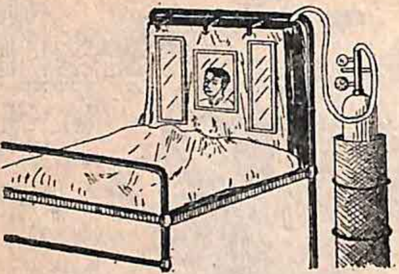
Although the oxygen present in the air is sufficient to satisfy the needs of a normal healthy person breathing under ordinary conditions, there are times when it is essential for a person to breathe in pure oxygen.

Mountaineers and airmen who go far above the earth take with them a supply of oxygen, for there the oxygen

Welding.

Climbing to dizzy heights.

content of the air is not sufficient and they find it difficult to breathe. In hospitals, too, this gas is used by doctors.



An oxygen tent.

A person suffering from damaged lungs is not able to breathe very well. The oxygen he takes in is not enough for his needs. The patient is laid in bed and a special tent placed over his face. Oxygen from a container is passed into the tent. Under these conditions he receives treatment. When he is well again, the tent is removed and he is able to breathe ordinary air again.

Hydrogen Peroxide. This substance is a colourless, syrupy liquid. It contains more oxygen than any other substance and tends to liberate it readily. Because of this it is used as a household bleach and as an antiseptic. Since it decomposes readily into water and oxygen in the light, even at ordinary room temperature, it is stored in brown bottles and kept in a cool and dark place.

Hydrogen peroxide is generally chosen to bleach delicate materials such as hair, feathers, silk and wool, since it does not damage these materials, unlike the more powerful bleaching agent chlorine.

A very weak solution of hydrogen peroxide is used as an antiseptic for cleaning infected wounds. Its action, however, is only momentary. Large amounts of it should not be used for this purpose as the oxygen liberated tends to damage the skin and prevent the wound from healing.

Chapter Activities

Outdoors

1. Visit a factory where oxygen is manufactured. During your tour of the premises try to understand everything you see.

2. Visit a workshop where welding is done and watch the welders at work. Be careful to protect your eyes with a blue glass.

For your wall newspaper

Make a large sectional drawing to show how oxygen is prepared in the laboratory. Label the drawing.

Note-book exercises

1. Write a summary of this chapter.

2. The story of how oxygen was discovered is an interesting one. Consult books in your science library and prepare a note for a class discussion on the subject.

At home

Use the chemistry set described in the last chapter to help you to prepare oxygen at home. Look for Hydrogen peroxide and Condys (potassium permanganate) in the medicine cupboard at home. Fit a bottle with a one-holed stopper and a delivery tube. Let the free end of the delivery tube dip into a large basin three-fourths full of water. Place your home-made beehive-shelf over the end of the tube to support a tall glass bottle in which the gas is to be collected. Pour a little hydrogen peroxide into the first bottle and add to it a pinch of Condys. Bubbles of oxygen will be seen coming from the mixture and the gas will soon displace the water in your 'gas jar'. When all the water has been displaced, cork the 'gas jar' and test the gas contained in it by means of a glowing splinter.

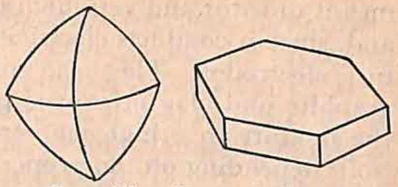
CHAPTER VII

CARBON AND ITS COMPOUNDS

CARBON is quite remarkable among the elements in that its atoms combine with one another as well as with those of many other elements. The compounds thus formed are over a million; in fact, there are more carbon compounds than those of all the other elements together. On account of this the chemistry of carbon and of its compounds is usually studied as a separate branch of chemistry called Organic Chemistry. The complex substances which compose the tissues of living things are included in this group and many others, such as dyes, plastics and numerous medicinals as well. In this chapter, however, we confine ourselves to a study of the element itself and of a few of its common compounds.

Allotropy of Carbon. It is difficult to believe that the wonderful diamond, most valuable of the gems, is for all its brilliance, chemically speaking, the same substance as charcoal and graphite. When an element, such as carbon, possesses the property to exist in two or more different physical forms which possess different physical properties, these forms are called allotropic forms of the element. Although diamond, charcoal, and graphite are unlike each other with respect to colour, hardness, relative density and many other properties they are identical in their chemical reactions. Equal weights of each of the three substances in the pure state when burnt in oxygen yield equal amounts of carbon dioxide. This proves that just like pure charcoal, diamond and graphite are also one hundred per cent carbon. Both diamond and graphite are crystalline forms of carbon: diamond crystals are hexagonal, whereas graphite crystals are octahedral.

Diamond. This is a crystalline form of carbon found in many parts of the world, chiefly in South Africa.



Crystalline forms of Carbon.
Diamond, Graphite.

Diamond is highly prized as a gem. In the pure state it is a colourless crystal, but the presence of minute quantities of foreign materials gives it a tinge of colour. The wonderful sparkle and play of colour possessed by a diamond with no serious flaws can be emphasised by proper cutting.

Diamond is the hardest of all substances and insoluble in all liquids. On account of these properties it is of great commercial value. It is used as a point for drills used in mining or oil-prospecting, for cutting glass or other diamonds, as the teeth of a saw used for cutting rocks and for other kinds of cutting and polishing operations.

Small diamonds can be made artificially by subjecting carbon to high pressure and temperature.

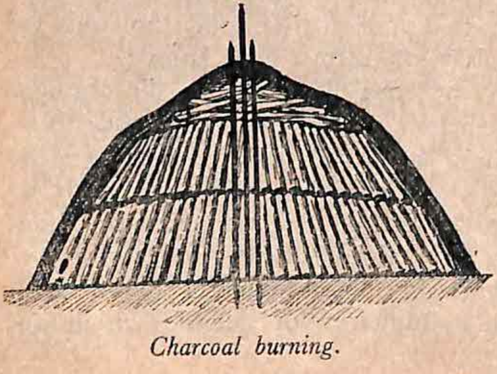
Graphite. Although graphite is found in nature, large quantities of it may be prepared artificially by heating coal to a very high temperature in an electric furnace. Graphite offers a strong contrast to diamond: not only is it black in colour, but it is the softest solid known.

Graphite crystals are soft, flat plates and as the crystals easily slide over each other the substance makes a useful lubricant. Moreover, it has a very high melting point, resists chemical reactions and does not catch alight easily. It is therefore used under conditions of high temperature when a liquid lubricant such as oil would disintegrate and cause sticking, slipping or chattering of the machine parts. Graphite is also used for the manufacture of crucibles which are meant to withstand very high temperatures without melting and, since it conducts electricity well, it is used to manufacture electrodes. The 'lead' of pencils is made by mixing graphite and clay in proper proportions and then heating the mixture to a high temperature. Pencils are 'hard' or 'soft' depending on the proportion of graphite in the 'lead'. A 'hard' pencil contains a smaller proportion of graphite than a 'soft' pencil.

Non-Crystalline Forms of Carbon. Coal, coke, charcoal and soot are non-crystalline forms of carbon.

Coal is a very impure form of carbon containing minerals and vegetable debris derived from plants which flourished millions of years ago. It is used chiefly as a fuel and in the production of coal-gas.

When coal is heated in the absence of air, coke and coal-gas are produced. In this process of coke production a large number of useful by-products are obtained such as tar, used for spraying roads; benzene, used in motor spirit and for making aniline which is converted into dyes and drugs; phenol, used for making dyes and drugs such as aspirin; naphthalene, used for moth-balls and for manufacturing dyes, and many others. Coke is chiefly used in the extraction of iron from its ore.



Charcoal burning.

There are several varieties of charcoal. Commercially, the most important are wood-charcoal and animal charcoal.

Wood-charcoal is produced by slow partial combustion of wood in a limited supply of air. In many of our villages the inhabitants prepare this variety of charcoal for domestic use. They do this by arranging logs of wood in the form of a mound. The stack of wood is then covered over with earth. A few holes are made at the bottom of the mound so as to admit a small amount of air and thereby allow the logs to burn. Two or three weeks after the wood has been lighted, the supply of air is cut off by blocking the air-holes. Thereafter the wood that has changed to charcoal is dug out of the mound.

Valuable by-products are lost in the atmosphere by the method described. When charcoal is manufactured commercially, care is taken that the by-products are separately collected, the main one being creosote which is a valuable preservative for timber.

Wood-charcoal has the property of absorbing large quantities of gases, many times its own volume. It can also absorb coloured substances from solutions in water. Because of this it is used for purifying the city water supply. When water is allowed to filter through charcoal it is decolourised and deodorised. Charcoal is also used in the manufacture of gas-masks.

Charcoal made by heating degreased bones in a limited supply of air is called animal charcoal. This form of charcoal is commercially used to decolourise the juice of raw sugar during sugar refining.

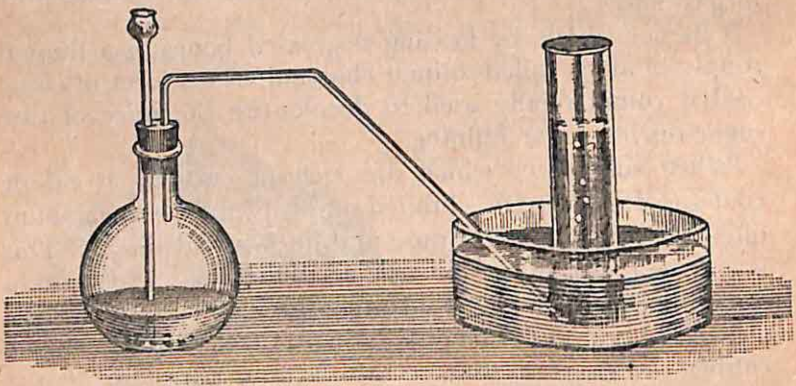
When substances which are rich in carbon, as oil or coal-gas, are heated in a limited supply of air, a large amount of carbon is formed in a pure and finely-divided state. This is known as lamp-black or soot. The chief uses of soot are in the manufacture of paints, printing ink, carbon paper, typewriter ribbons, and shoe polish. Soot mixed with vulcanized rubber gives tyres resistance to wear and abrasion.

Oxides of Carbon. In this category are the two compounds of carbon, both of which are gases, called carbon dioxide and carbon monoxide, formed as the result of a union of carbon atoms with oxygen atoms.

You already know that there is a small proportion of carbon dioxide present in the atmosphere. Carbon monoxide, however, does not occur in nature. It is present as a component of several important industrial gases such as those used for heating furnaces and running large gas-engines.

Carbon Dioxide, CO_2. Not all substances form carbon dioxide when they burn, but only those that contain the element carbon. Carbon dioxide may therefore be obtained by burning any fuel containing carbon. The gas may also be prepared by strongly heating any form of calcium carbonate, such as limestone, marble and chalk (not the chalk used in the classroom). As it is not convenient to prepare carbon dioxide by any of the two ways just mentioned, carbon dioxide is prepared in the laboratory by the action of acid on calcium carbonate.

Fit a two-holed stopper to a flask and insert a thistle funnel through one hole and a delivery tube through the



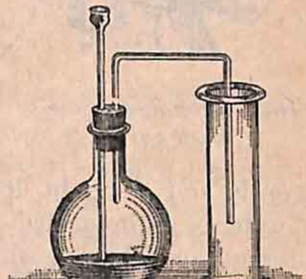
Arrangement for collecting carbon dioxide by the displacement of water.

other. Place a few pieces of marble chips in the flask and arrange the delivery tube so that one end of it dips beneath a beehive-shelf placed in a trough of water.

Fill several jars with water and cover each with a greased glass plate. Take one of the jars, invert it, and lower it carefully into the trough of water. Put it over the top hole of the beehive-shelf and remove the glass plate.

Pour dilute hydrochloric acid down the thistle funnel. As the acid touches the marble chips, there is a chemical reaction and carbon dioxide is given off. Make sure that the lower end of the thistle funnel dips below the surface of the acid in the flask or the gas will escape through the funnel instead of entering the delivery tube. Though the gas is fairly soluble in water, it can be collected by the displacement of water since large volumes of it are produced.

Another method of collecting the gas is by the upward displacement of air. In this method the beehive-shelf and trough of water are replaced simply by a gas jar. Since carbon dioxide is heavier than air it sinks down to the bottom of the jar displacing the lighter air.



Arrangement for collecting carbon dioxide by the upward displacement of air.

Carbon dioxide is a colourless gas with a faint smell and sharp taste.

It is not combustible nor does it sustain combustion. Thrust a burning splinter into a jar containing gas. The flame is at once surrounded by the gas and since no more oxygen can get to it, it is quickly extinguished.

The fact that carbon dioxide is not combustible shows that it cannot further combine with oxygen; the fact that it does not sustain combustion shows that it is a stable compound which does not easily part with an oxygen atom for sustaining combustion.

Lime water becomes milky when poured into a jar containing the gas. This property distinguishes carbon dioxide from all other gases.

The gas is about one and a half times heavier than air.

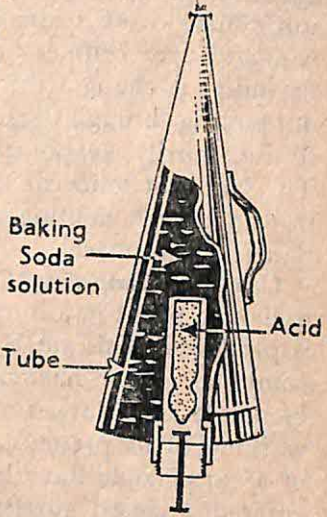
How carbon dioxide can be poured from one gas jar to another.

Pour carbon dioxide from one gas jar into another by inverting a jar containing it over an 'empty' jar (i.e. a jar containing air). Now test for the presence of carbon dioxide in the lower jar, either with lime water or by means of a burning splinter. Because it is a heavy gas it collects in low places such as old wells and mines. Anyone going into these places must previously test them by lowering a lighted candle. If the candle is extinguished it means that carbon dioxide is present and there is the danger of suffocation, since the air has been displaced by carbon dioxide.

As already mentioned, carbon dioxide is soluble in water. It dissolves in water forming a weak acid called carbonic acid. Blue litmus paper turns red when put into the solution.

The fact that carbon dioxide puts out a fire is made use ofin fire extinguishers.

A fire extinguisher is filled with a strong solution of baking soda (sodium bicarbonate). Above the plunger at the lower end is a bottle containing acid. To work the extinguisher, the bottom of it is banged against the ground. This action results in the breaking of the bottle. When the acid comes in contact with the solution of baking soda a large quantity of carbon dioxide is produced. The gas exerts a pressure on the liquid forcing it up the side tube and through the nozzle. The liquid quenches the fire while the gas smothers it.



The inside of a fire extinguisher.

Soda water is made by exerting considerable pressure on carbon dioxide and forcing it into water where it dissolves. When you remove the cap from a soda-water bottle the pressure is lessened and carbon dioxide comes fizzing out.

Baking powder used in the making of cakes is a mixture of sodium bicarbonate and cream of tartar. When baking powder is moistened, the two substances of which it is composed react with one another and carbon dioxide is evolved. Cakes are made to rise by adding baking powder to the cake mixture and then adding water. As bubbles of carbon dioxide are given off they puff up the cake. The heat from the oven not only cooks the cake but also hastens the production of carbon dioxide.

Carbon dioxide can be easily changed into a liquid and then frozen into a solid. Solid carbon dioxide is very cold and looks like ice. In this form it is sold as 'dry ice'. Blocks of 'dry ice' are cut into smaller blocks and used as a cooling agent for preserving ice-cream and certain perishable foodstuffs such as meat and fish. 'Dry ice' has three main advantages over ordinary ice. Firstly, it is colder than ice; secondly, it changes directly to gas on evaporation, without passing through the liquid state and is, therefore, cleaner to use; thirdly, evaporation takes place at a very slow rate. The fact that solid carbon dioxide changes directly to gas instead of first melting to liquid has given it the peculiar name of 'dry ice'.

Carbon Monoxide, CO. When carbon or a compound of carbon is burnt in a limited supply of air, carbon monoxide is produced. This gas is a deadly poison because it readily combines with *haemoglobin, the oxygen carrier of the blood. It is colourless and odourless and therefore gives no warning of its presence. It is present in the exhaust fumes of a car. People have been known to die when they have entered a closed garage in which a car engine has been left running for some time. Carbon monoxide is inflammable and burns with a blue flame to produce carbon dioxide.

Carbon monoxide is chiefly used for heating purposes. Because it readily combines with oxygen it is called a reducing agent. When passed over metallic oxide such as iron oxide, lead oxide, copper oxide and so on, it combines with the oxygen part of the oxide thus reducing the oxide to its metal. For this reason it is used to liberate metals from their oxides.

Calcium Carbonate, $CaCO_3$. This very important substance is found in nature as chalk, limestone and marble. When any of these substances are heated strongly carbon dioxide is given off and a white residue is left called calcium oxide,

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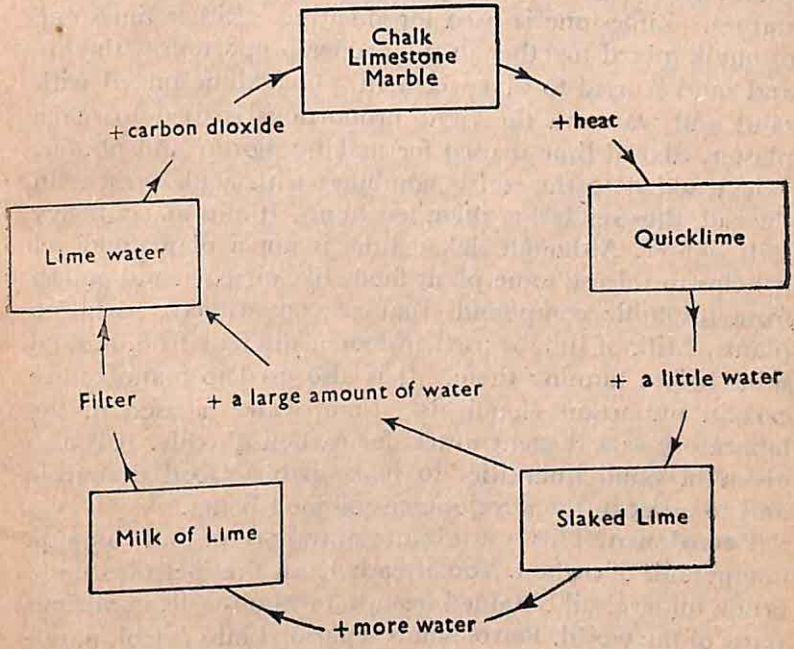
* *See* Chapter 11.

CaO (quicklime). If a little water is added to quicklime a chemical reaction takes place during which heat is evolved and the quicklime combines with water to form a fine, soft, white powder called calcium hydroxide, $Ca(OH)_2$



How calcium carbonate can be changed to other substances.

(slaked lime). If a small amount of water is added to a large amount of slaked lime a portion of slaked lime dissolves, whereas the remaining portion is held in the form of a suspension. This is called milk of lime. If, however, a large amount of water is added to a small amount of slaked lime, it dissolves to give a clear solution called lime water. Since milk of lime is a suspension of slaked lime in water, and lime water is a saturated solution of slaked lime, the chemical formula for both is the same as that of slaked lime.

Each of the substances mentioned has important uses. Chalk is used for improving the soil. Marble is carved into statues. Limestone is used for smelting. Either limestone or chalk mixed together in the proper proportion with clay and sand is used to make cement. Quicklime mixed with sand and water in the right proportions is used to make plaster. Slaked lime is used for making mortar and plaster. When added to the soil it combines with acids present in the soil, thus rendering them less 'sour'. It also makes heavy soils lighter. Although slaked lime is not a plant food yet it helps to release some plant foods like nitrogen and potash from insoluble compounds that are not directly useful to plants. Milk of lime is used to loosen the hair from animal skins before tanning them. It is also used to manufacture certain important chemicals. Lime water is used in the laboratory as a reagent to test for carbon dioxide. It is also given in small quantities to make babies' food digestible and to assist in the development of good bones.

Petroleum. This is a mixture of important and common compounds of carbon. You already know that petroleum is a crude mineral oil obtained from natural oil-wells in various parts of the world. Petroleum is separated into petrol, paraffin, fuel oil and other constituents. The oils are used as fuels. For example, petrol is used as a fuel in the internal combustion engines of cars and aeroplanes; paraffin oil is used as a fuel in oil-stoves and lamps; fuel-oil is used as a fuel in the diesel engines of heavy lorries and ships. Lubricating oils, such as vaseline and paraffin wax, are also derived from petroleum.

CHAPTER ACTIVITIES

Outdoors

1. Try to visit the following places of interest: (*a*) a gas works; (*b*) an aerated water factory; (*c*) a lime kiln; (*d*) a blast furnace and (*e*) a cement factory.

2. Ask an ice-cream vendor to show you the 'dry ice' he uses to preserve his supply of ice-cream.

For your wall newspaper

Design and make a chart to show how a few of the important compounds of carbon are used in daily life.

Note-book exercise

Describe your visit to any of the places as mentioned under the sub-heading 'Outdoors'.

Laboratory work

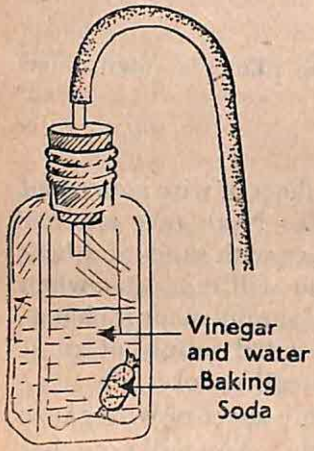
1. Place a small piece of coal on a sheet of wire gauze and heat it strongly over a bunsen flame. Next, take another piece of coal in a crucible, cover it over with sand and heat it strongly over a bunsen flame. You will note that when coal was allowed to burn in a plentiful supply of air it changed to cinder but when burnt in a limited supply of air it changed to a light spongy substance called coke.

2. Place a small piece of marble on a sheet of wire gauze and heat it strongly over a bunsen flame. You will note that it changes to a white opaque substance. This is quicklime. After allowing the quicklime to cool, transfer it from the gauze to a test tube. Add a few drops of distilled water to it. Note that heat is evolved as the quicklime changes to slaked lime. Add more distilled water and filter the milky liquid. The filtrate is lime water. Pour off the filtrate into a test tube and note the cloudiness formed when you breathe

by means of a bent tube through the clear liquid. The carbon dioxide in your breath reacts with the lime water to form calcium carbonate which settles down after some time to the bottom of the test tube. Once again filter the liquid in the test tube and add some dilute hydrochloric acid to the residue. There is immediate effervescence and carbon dioxide is evolved.

At home

You need a bottle, baking soda (sodium bicarbonate), vinegar, water, tissue paper, a one-holed stopper, glass and rubber tubes, to set up the apparatus to produce a ready supply of carbon dioxide. Mix vinegar and water in equal parts and pour the mixture into the bottle to fill half of it. Fix the glass tube into the stopper and attach the rubber tube to it. Make a packet of baking soda by wrapping the powder in tissue paper. Drop the packet into the bottle and put the stopper on quickly. When the contents of the bottle bubble, colourless carbon dioxide comes from the rubber tube. You can now proceed to test the properties of the gas as given in the text.



The carbon dioxide supply bottle.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces : statues, colourless, slaked lime, babies' food, diamond, ore, mortar, lime water, soil, burn, coal, fuels, refrigerating, oxides, carbon, smelting, paints, graphite, quicklime, water supply, gem, smell, coke, water, air, acid, soot, cement, 'leads', charcoal, calcium carbonate, metals, wood, electrodes, extinguish fires, pencils, drills, plaster, combustion, carbon dioxide, lubricant, carbonic acid, coal-gas, oil-wells, fuel oil, blue, poisonous, iron, holes, degreased, reducing, petrol, by-products, carbon monoxide, mineral waters, paraffin oil, petroleum.

Carbon occurs in two crystalline forms,—and—and in several non-crystalline forms such as—,—,—and—. Diamond is valued as a—. Because of its hardness it is used as a point for—. Graphite is used in the manufacture of—for —,—and as a—. Coal is used as a fuel and also in the manufacture of—. A number of useful—are obtained during the manufacture of coal gas. When coal is heated in the absence of—, coke is obtained. Coke is used to help produce —from its—. When—and—bones are heated in a limited supply of air, wood charcoal and animal charcoal are produced respectively. Charcoal is used as a fuel and also for purifying the city—. Soot is produced when some substances which are rich in—are heated in a limited supply of air. Soot is chiefly used to manufacture—.

Carbon dioxide is prepared in the laboratory by the action of—on—. It is—and has a faint—. It does not—nor does it sustain—. It turns lime water milky. It is heavier than air. It dissolves in—to form—. It is used to—, to manufacture—and as a—agent. —is formed when carbon or a compound of carbon is burnt in a limited supply of air. It is a colourless, odourless gas. Although it burns with a—flame it does not sustain combustion. It is a—gas. Since it is a—agent it is used to separate—from their natural—.

When chalk, limestone and marble are strongly heated they are changed to—. Water added to this substance changes it to—. If the water used is in excess,—will be produced. Chalk is used for improving—; marble is carved into—and limestone is used for—. Either chalk or limestone is used in the manufacture of—. Quicklime is used to make —. Slaked lime is used to improve the soil and for making —and plaster. Lime water is used to test for—and also to make—digestible.

—is obtained by boring—in the earth and striking—. It is separated into—, —and—. These oils are used as—.

CHAPTER VIII

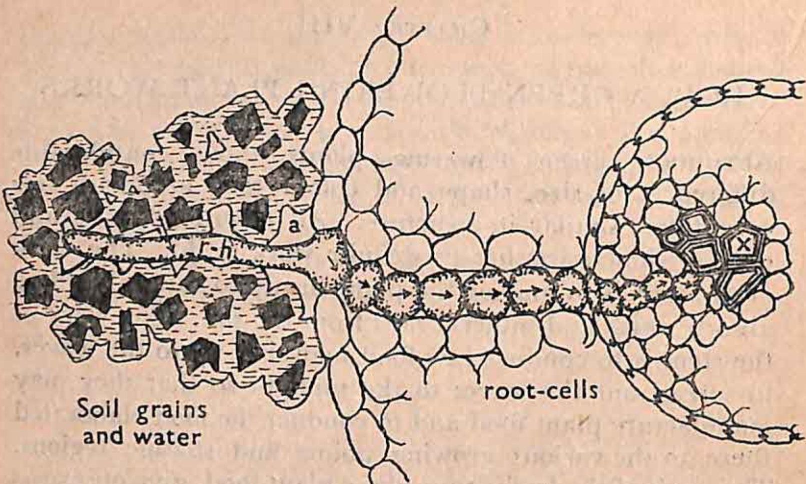
HOW A GREEN FLOWERING PLANT WORKS

ALTHOUGH green flowering plants show considerable differences of size, shape and colour they are, with few exceptions, similar in structure. All have four parts and each of these parts has its definite work to do. The work of the root is to anchor the plant firmly to the soil and to absorb water and mineral salts from the soil. The work of the stem is to conduct raw food materials up to the leaves, to spread out the leaves to the sunlight so that they may manufacture plant food and to conduct the food elaborated there to the various growing points and storage regions. The work of the leaf is to produce plant food, give off excess water in the form of vapour and afford a means by which gases are interchanged between the atmosphere and the plant body. The work of the flower is to help the plant to reproduce its kind.

Absorption by the Roots. Some of the minerals present in the soil are necessary to plants. These minerals are only available to plants in the form of solution. When rain passes through the soil it dissolves these minerals and forms a weak solution of them.

The numerous fine hairs present on the roots of a plant, called root-hairs, push their way between the soil particles around which the weak solution of mineral salts lies. Inside the root-hair is the sap which consists of water containing both minerals and food substances. Between the soil water and the sap is the lining of the root-hairs. To understand how the soil water enters the root-hair it is necessary to know what is meant by diffusion and osmosis.

When a lump of sugar, the solute, is put into a cup of



To show how water enters a root-hair and passes to the xylem.
(Highly magnified.)
Arrows indicate the path taken by the water.
a, air-space; r-h, root-hair; x, xylem.

water, the solvent, the molecules of sugar and water spontaneously intermingle with one another until the sugar molecules become uniformly distributed throughout the water. This movement of the molecules of a solute through a solvent to form a solution is called diffusion. By means of the process, in the given example, the molecules of sugar passed from the region where they were highly concentrated (the lump) to the region where they were less concentrated (the solvent).

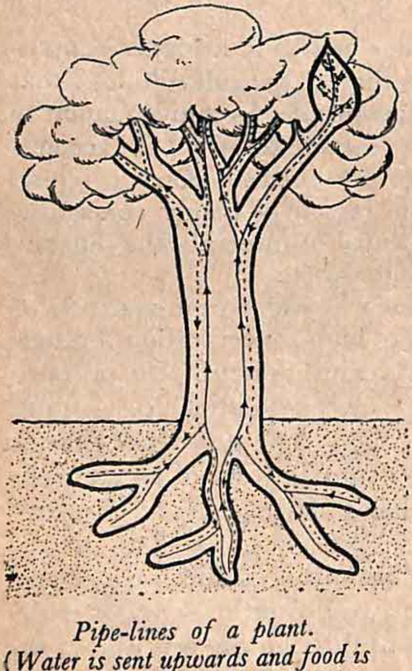
Diffusion can in certain cases take place through a membrane, but which substances are passing through depends on the nature of the membrane. Water and the substances dissolved in it can pass through a permeable membrane such as filter paper. There is, however, a kind of membrane which only allows water and certain dissolved substances to pass through while it prevents the passage of other dissolved substances. Such a membrane is known as a semi-permeable membrane, an example of it is the inner lining of the cell wall of a plant cell such as the root-hair.

Sometimes too much of fertiliser is added to a soil and as a result the proportion of water becomes less outside than inside the cells. Water now diffuses out of the cells and the plant suffers from drought although there may be a large amount of water around its roots. It is because of this that the majority of land plants cannot live in soil flooded with sea-water, due to excess of salt in solution.

The sap in the root-hair has generally a higher concentration of mineral salts than that of the soil solution; that is to say, the number of water molecules for a given quantity of salt is less in the sap than in the soil solution. On account of this, water molecules diffuse into the cell, from the region of lower concentration to the region of higher concentration. The mechanism of the entry of mineral salts into the root is not yet completely understood.

The passage of a solvent such as water from a region of low concentration to a region of high concentration through a semi-permeable membrane is called osmosis. The pressure which forces a solvent from a weak solution to a strong solution is called osmotic pressure. The process of osmosis regulates the passage of water into and out of a plant cell, the direction of movement being determined by the concentration of solute inside and outside a cell. The process continues until pressure equilibrium is established between the two solutions, or, in other words, until the water molecules pass in opposite directions through the cell wall at the same rate.

When water enters a root-hair cell, the cell becomes turgid and the water that accumulates within the cell exerts a certain pressure on the surrounding cell wall. Counteracting this pressure is the pressure exerted by the cell wall which being elastic tends to regain its original shape. When the cell wall recoils, part of the fluid contents are forced through the cell wall into the adjacent cell, and thereafter, by the same process, from cell to cell, from the periphery of the root to its centre. After water has left the root-hair cell it becomes flaccid and again absorbs soil solution. The intermittent pumping action which takes place in the cells of the root as they become alternately turgid and flaccid gives rise to considerable pressure called root-pressure. As a result of this pressure, water is forced into the pipe-like vessels that run through the axis of the plant.



Pipe-lines of a plant.
(Water is sent upwards and food is sent downwards.)

Conduction by the Stem. We have just read how the roots take in water and mineral salts. Much of this water is given off by the leaves. You will shortly read how the leaves manufacture food. This food is distributed round the plant. The transporting mechanism of the plant must therefore be a double one. Water tubes, known as xylem, and food tubes running alongside them, known as phloem, extend from the root to the tips of the veins in the leaves forming a continuous passageway.

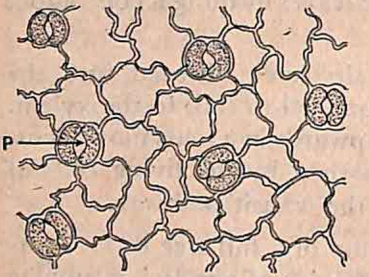
When water and mineral salts have diffused into the root-hairs, they pass inwards from cell to cell, to the xylem. Once in these tubes they move upwards in a mass movement. Dissolved mineral salts are absorbed by the living cells of the stems and leaves all along the transit pathway.

The passage of water to the top of a tall tree is not completely understood. The xylem consists of non-living tubular cells with narrow bores. They are well fitted for rapid transport of water, although the cross walls between the cells in a row are bound to slow up the process of transportation. Among the factors responsible for the upward movement of water is the driving force of root-pressure and the pulling force due to the evaporation of water in the leaves and the consequent suction that is created. Another factor is capillarity, the force by which water spontaneously rises in narrow tubes having a cross-section not larger than a hair (*Capillus* in Latin, hence the name capillarity).

The food-conducting route operates in the opposite direction. Food manufactured in the leaf moves downwards along the phloem to the roots. Food made in excess to the requirements of the plant is stored in the stem and root.

Functions of the Leaf. Since plants absorb more water than they require for their needs there must be some way to get rid of the excess water. The chief agent that helps the plant in this important work is the leaf. The giving off of water vapour from within the plant body through its leaves and stem is known as transpiration.

Water which is not used by the plant is brought to the cells of the leaf by the xylem and evaporates from these cells to collect in the air spaces between them. From here the water vapour escapes into the atmosphere through small, microscopic pores called *stomata. The loss of water takes place chiefly from the under-surfaces of the leaves because the under-surface has always a larger number of stomata. Each stoma is flanked by two bean-shaped cells called guard cells which, to a certain extent, regulate transpiration by coming together and thereby lessening the size of the opening, or by moving apart, and thereby increasing the size of the opening.



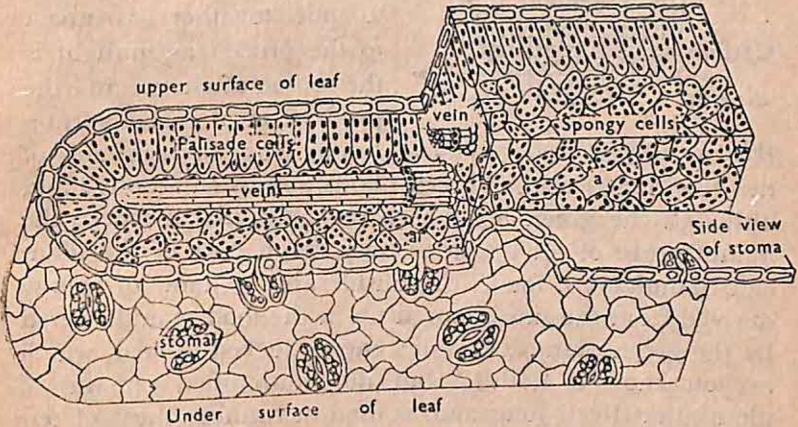
A magnified view of the portion of the skin on the under-side of a leaf showing the pores (p).

The process of transpiration is of vital importance to the plant. By it, as already mentioned, the plant can get rid of excess water absorbed by the roots. Transpiration sets up a suction force which helps in the ascent of water. When water is converted from the liquid state to the vapour state a considerable amount of heat is lost and thereby the plant becomes cooler. Finally, a constant supply of raw food materials in solution is supplied throughout the plant body as a result of transpiration.

The rate of transpiration is affected by certain factors. The rate increases by day and diminishes at night. This is because the stomata remain fully open in the day and partially close at night. On days when the atmosphere is very dry it receives moisture very readily, but on very humid days the atmosphere being nearly saturated with moisture can receive very little water vapour. It follows then that

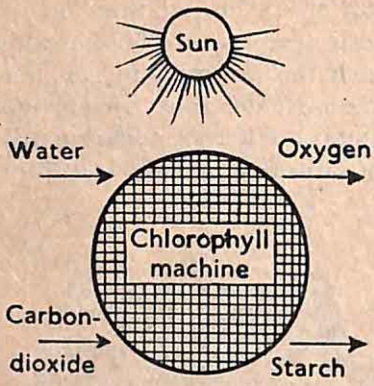
*Stomata is the plural form of stoma

the rate of transpiration is slower on humid than on dry days. An increase in atmospheric temperature increases the quantity of water vapour which the atmosphere can hold and transpiration takes place at a greater rate. Air currents remove water vapour from around the leaves, consequently, the air around the leaves is not saturated and the transpiration rate increases.



Looking into a leaf.
(Highly magnified.)
Palisade cells and spongy cells contain chlorophyll bodies.
a, air-space.

The question of how green plants manufacture their food has puzzled scientists for many years and is still a mystery. The broad outline of the process, however, is known. Tiny bodies, called chloroplasts, present in the cells of the leaf contain a green pigment called chlorophyll. With the help of the chlorophyll in them these bodies are able to manufacture simple carbohydrates such as sugar and starch from



What a chlorophyll machine can do.

carbon dioxide and water absorbed from the air and the soil respectively, oxygen being given off as a by-product. Energy for the process is provided by sunlight. The name photosynthesis (*photo*, light; *synthesis*, to put together) is given to the process as sunlight is the source of energy and the production of carbohydrates results from the synthesis of raw food materials. All green plants possess chlorophyll and although the green leaves are the chief places where the manufacture of food is done, any green part of the plant can manufacture food. A considerable amount of energy derived from the sun is stored up in the food manufactured by the green plant. The sun's energy locked in coal, which as you know is nothing but the mummified remains of plants that lived long ago, is used in running most of our industries.

The plant uses up this food material to derive the energy required to perform its life activities. The process by which this is done is called respiration. It is essentially an oxidation process.

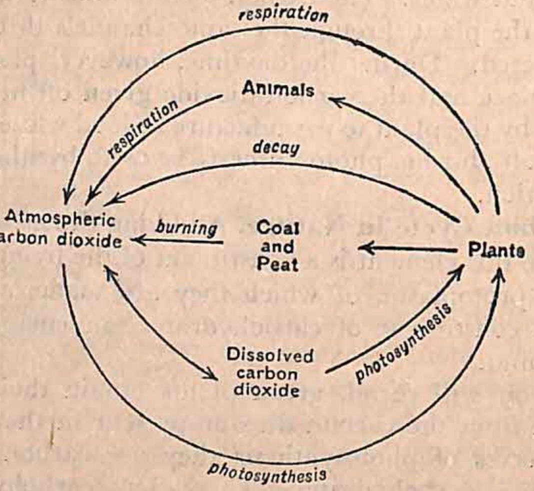
Air enters the plant body through the stomata and also through special openings called lenticels which are developed on the branches. The latter are open both day and night. The oxygen present in the air diffuses through a network of air cavities and intercellular spaces into the cells. Here it combines chiefly with the sugar present in the cell to release energy in the form of heat and form carbon dioxide and water. The carbon dioxide thus formed diffuses out of the plant through the same channels through which air entered. During the daytime, however, photosynthesis takes place and the carbon dioxide given off in respiration is used by the plant to manufacture its food while the oxygen given off during photosynthesis is used by the plant for respiration.

Carbon Cycle in Nature. All living things need carbon because this element is a constituent of the living substance, called* protoplasm, of which they are made, and because it is a constituent of carbohydrates, an energy-providing compound.

As you will recall, green plants obtain their supply of carbon from the carbon dioxide present in the air, and by the process of photosynthesis they use carbon dioxide to synthesise carbohydrates. Thereafter, carbohydrates are elaborated into other compounds which are transformed into protoplasm. Thus the transfer of carbon into energy-providing compounds begins with the green plant. Animals obtain carbon from green plants either directly when herbivorous animals eat green plants or indirectly when these animals are in turn eaten by carnivorous animals. In animals too, carbohydrates are changed into other compounds which are transformed into protoplasm. During the process of respiration the energy available in carbohydrates is liberated and some of the carbon dioxide removed from the air is thus returned.

When animals and plants die, their bodies decay and as a result of this process, carbon dioxide, in itself a compound with no available energy at all, is returned to the atmosphere. In this way a carbon cycle exists in nature by which carbon circulates through a succession of living things, generation after generation, over and over the same route:

*See Chapter 10.



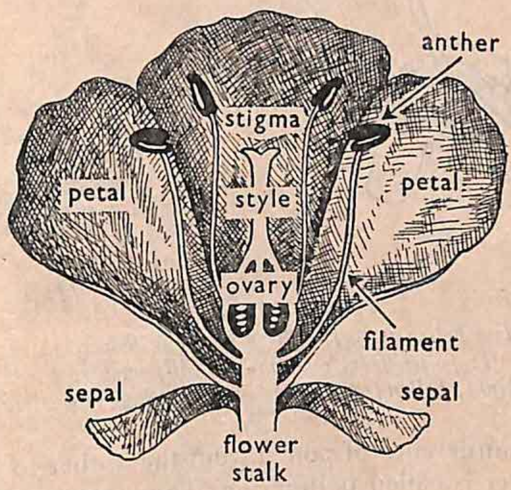
The carbon cycle.

from carbon dioxide to energy-providing compounds and back again to carbon dioxide.

The carbon in the form of carbon dioxide taken out of the air millions of years ago by plants, which thereafter gradually changed to coal, petroleum and natural gas, is returned to the air in the form of carbon dioxide when these fuels are burnt. As a result of the carbon cycle process, the proportion of carbon dioxide in the air remains fairly constant.

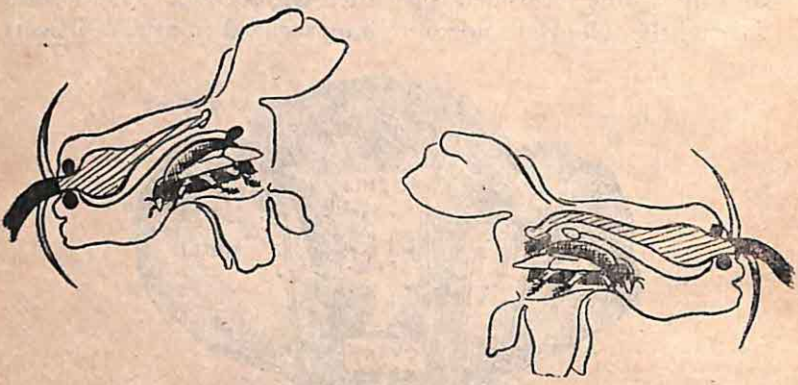
Reproduction by the Flower. The flower is an aggregation of structures concerned with the process of reproduction which leads to the formation of seeds. In most plants, flowers are borne in a group towards the end of a stem or branch. Such a group is called an inflorescence.

A typical flower consists of four distinct structures. The outermost set is made up of green, leaf-like structures. Each of these is called a sepal and the whole ring of sepals is called the calyx. The function of the calyx is to enclose and protect the other floral parts. The next set is composed of brightly coloured leafy structures. Each of these is called a petal and the whole set of petals is called the corolla. The corolla is brightly coloured and sometimes scented to attract insects to the flower. The stamens are the third inner set. Each stamen consists of a stalk or filament which supports a terminal anther containing pollen grains. The innermost part of the flower is called the pistil. It is made up of three parts: the top, which is usually rough and sticky, is called the stigma; the base, which is made up of a small chamber, is called the ovary; the narrow tube which joins the stigma to the ovary is called the style. The ovary contains a number of tiny ovules which eventually form the seeds. Of these four sets, the pistil and stamens are called essential



Parts of a flower.

sets because they are directly concerned with the reproduction of the plant. The calyx and corolla are called accessory sets since they are not directly concerned with the reproduction of the plant.



How pollen is carried from flower to flower.
Left: pollen from ripe anthers falls on bee.
Right: pollen from the bee's body reaching ripe stigma.

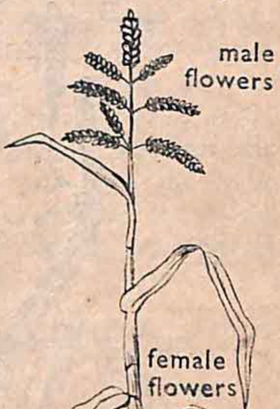
The transference of pollen from the anther to the stigma of a flower is called pollination. There are two methods of pollination: self-pollination and cross-pollination. In self-pollination the pollen grains are transferred from the anther to the stigma of the same flower. In cross-pollination the pollen grains of one flower are transferred to the stigma of another flower. Cross-pollination is effected by animals (chiefly insects and birds), wind or water.

Cross-pollination results in healthier offspring, more abundant seeds and, in many instances, new varieties of plants. Self-pollination, on the other hand, is more certain to take place, and more economical.

Most flowers are cross-pollinated by insects such as butterflies, moths, bees and so on. To attract these agents they are brightly coloured, scented and have a supply of nectar at the base of their corollas. Additional attractions are irregular-shaped corollas and modification of sepals into coloured leafy structures. Flowers pollinated by moths bloom at night and are white or yellow in colour to be as conspicuous as possible. Insect-pollinated flowers have sticky pollen grains and sticky stigmas so as to ensure pollination.

The Snapdragon is an example of an insect-pollinated flower. Its stamens and stigmas ripen on different days so as to make self-pollination impossible. Bumble bees push their way into the flowers to search for nectar. If the stamens happen to be ripe, they receive a quantity of pollen over their bodies. If they next fly to flowers in which stigmas are ripe, some of the pollen from their backs comes into contact with the stigmas. It is important to note that the pollen grains of a certain plant are only effective if put on the stigma of a flower of the same kind of plant. Insects do not haphazardly visit various kinds of flowers, but instead restrict their visits only to the flowers of a particular kind of plant. When the supply of nectar from the plant is exhausted they turn their attention to another kind of plant.

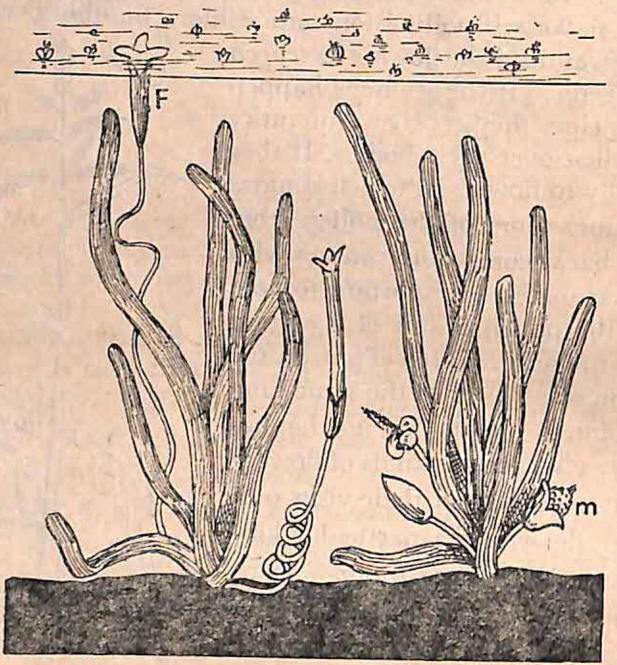
Certain flowers, especially those of grasses, are pollinated by the wind. Such flowers are small and



A wind-pollinated plant: the maize.

inconspicuous, emit no smell and do not secrete any nectar. The flowers are unisexual, that is, male flowers are segregated from female flowers in which there are only pistils. The anthers of wind-pollinated flowers produce an immense quantity of pollen grains because a large amount of pollen is wasted during transit from flower to flower. The stigmas are long and feathery and protrude some way out of their flowers.

The Maize plant is an example of a wind-pollinated

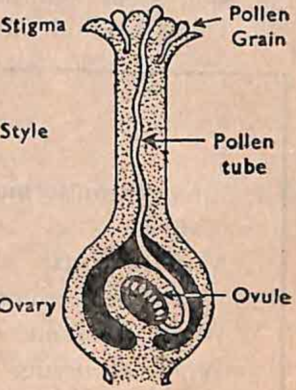


A water-pollinated plant: the tape-grass.
Male flowers are shown floating on the surface of the water.
Left: a female plant. Right: a male plant.
f, female flower; m, a cluster of male flowers.

flower. The male flowers are borne at the top of the plant while the female flowers are borne lower down. When the anthers burst, a shower of pollen grains is sent into the air. Some of the pollen grains fall on the stigmas of the female flowers lower down, but a considerable quantity is wasted.

A few aquatic plants are pollinated by water. A plant called Tape-Grass, known to botanists as *Vallisneria*, is an example of such a plant. In this plant male and female flowers are borne on separate plants. A large number of minute male flowers are borne by the male plant at the end of a flowering stalk. The flowering stalk gradually grows towards the water surface. Here the flowers become detached from the stalk and float on the surface of the water like a fleet of little boats. The female flowers are solitary and are borne by the female plant at the end of a flowering stalk. While the male flowering stalk is growing towards the water surface the female flowering stalk does the same and lifts the female flowers just above the surface of the water. Water currents bring the male flowers into contact with the female flowers. When this happens the anthers burst and the pollen grains stick to the stigmas.

When a pollen grain reaches the stigma as a result of pollination it swells up and develops a pollen-tube which grows down the style and finally passes into the ovary. A tiny fragment of the pollen grain passes down the pollen tube and fuses with the ovule to form a single cell. The fusion of the pollen grain with the ovule is commonly referred to as fertilisation.



Fertilisation.

CHAPTER ACTIVITIES

Outdoors

Search for and collect flowers in which (*a*) there are only stamens, (*b*) there are only pistils, (*c*) the calyx and corolla do not differ much in colour and shape, (*d*) the sepals are free, (*e*) the sepals are united, (*f*) the petals are free, (*g*) the petals are united, (*h*) the stamens are free, (*i*) the stamens are united to the corolla, (*j*) the stamens are united to one another, (*k*) the flowers are self-pollinated, (*l*) the flowers are cross-pollinated.

For your wall newspaper

1. Mount the flowers which you have collected. Write below each their special characters.

2. Make a large composite diagram of the drawings on pages 136, 138 and 141.

Note-book exercises

1. Write a note on the relation between the functions of the root, stem and leaf.

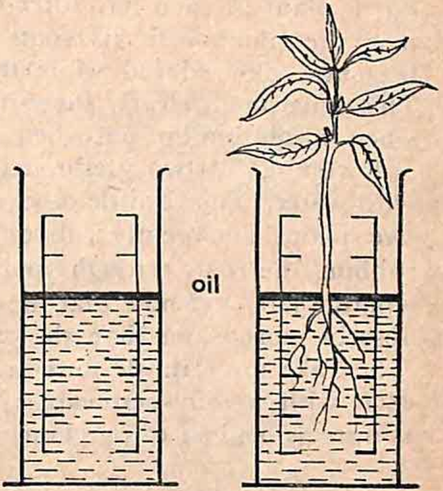
2. Copy this table into your note-book and fill it in.

	Photosynthesis (building up of carbohydrates)	*Respiration (breaking down of carbohydrates)*
1. Energy transformations		
2. Materials used		
3. Materials produced		
4. When occurring		
5. Where occurring		
6. Source of energy		

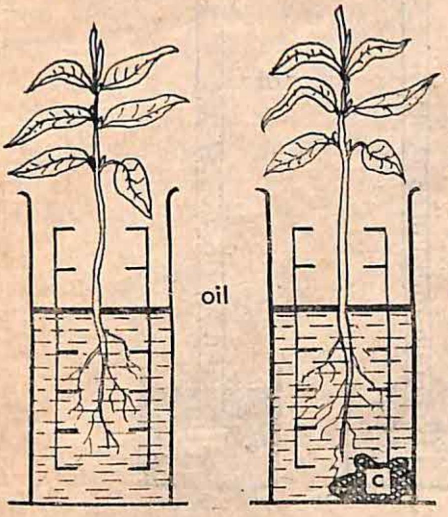
3. Describe the oxygen cycle, especially explaining how the proportion of oxygen in the air is maintained at approximately a constant value.

Laboratory work

1. Take two graduated jars and fill them with water up to the same level. Pour some oil on the water surfaces of both jars so as to prevent any water from evaporating. Put a plant into one of the jars with its roots well below the water surface. After a day or two you will observe that there is a fall in the water level of the jar containing the plant, showing that the roots have absorbed water. There is no fall in the level of water contained in the other jar which was set up as a control.



To show that roots absorb water.



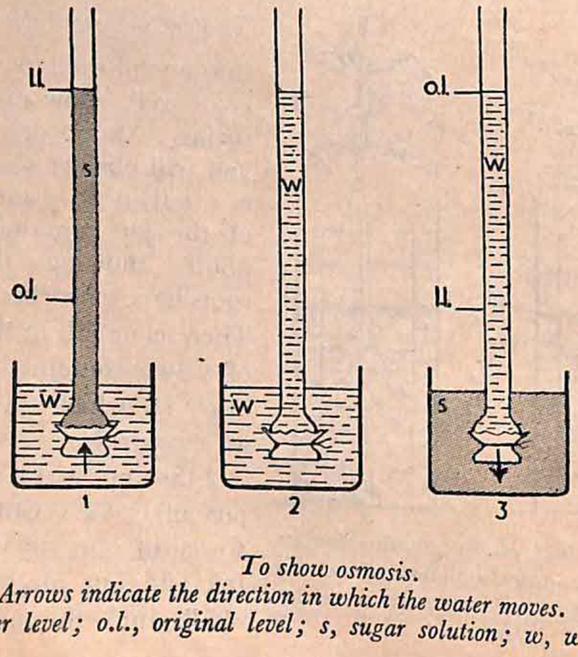
To show that plants absorb solutions. The jar on the left contains red ink. The jar on the right contains water and chalk (c).

2. Set up, as before, two jars of water. Colour the water of one jar with red ink and put pieces of red chalk into the other jar.

Put a plant in each jar. After some time you will observe that the plant with its roots immersed in the solution becomes coloured red while the other shows no change. This experiment clearly shows that roots absorb substances when in solution but not when in the solid state.

4. Again, fill two graduated jars up to the same level with water. Pour a little oil over the water surfaces. Take two plants and gently rub off the root-hairs of one by rubbing the roots through your fingers. Put the plants in separate jars, and note that the plant with root-hairs intact absorbs more water than the other.

5. Take three thistle funnels and cover the wide end of each with a semi-permeable membrane such as sausage skin, pig's bladder or parchment paper. Pour a strong solu-



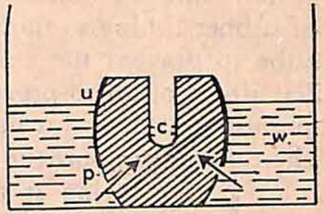
To show osmosis.

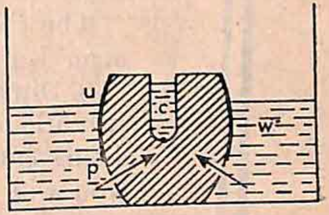
Arrows indicate the direction in which the water moves.

l.l., later level; o.l., original level; s, sugar solution; w, water.

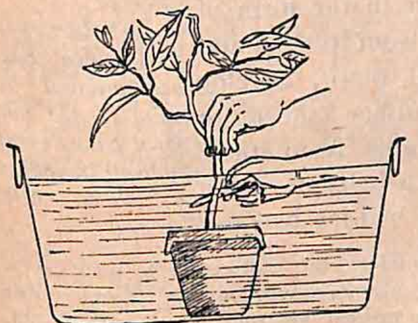
tion of sugar into the first funnel and some water into the second and third funnels. Adjust the levels of each liquid so that they are the same. Immerse the lower end of the first and second funnels in beakers of water and the third in a beaker containing a strong solution of sugar. Fix each funnel to a retort stand and leave them for some time. Can you explain why the levels of liquid in the stems of the three funnels vary?

6. Take a potato and cut one end level so that you can stand it in a trough of water. Pare off the skin from the lower half of the potato and scoop out a hole from its upper end. Put a few drops of copper sulphate solution in the hole. You will find that the amount of liquid in the hole gradually increases until finally it overflows. This experiment shows how cell to cell osmosis of the water takes place in a plant.





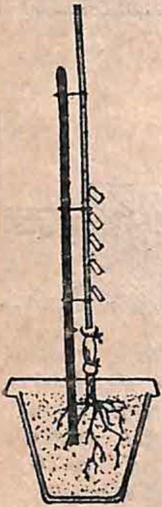
To show osmosis in a potato. Arrows indicate the direction in which the water moves. c, copper sulphate solution; p, pared part of potato; u, unpared part of potato; w, water.



Cutting a plant under water.

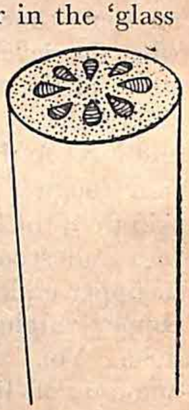
7. Do roots push water up the stem? Select a potted plant such as a Dahlia or a Sunflower and put it into a large tub filled with

water. Cut the stem as shown and fix a glass tube by means of rubber tubing to the[*] stump. Pour a little water into the tube to prevent the cut end from drying and then add a few drops of oil to prevent the water in the tube from evaporating. When this has been done, take out the pot from the tub and support the glass tube in an upright position by tying it to a stick. Now water the plant regularly. Watch how the water rises up the 'glass stem'. Mark the water level by tying labels to the tube every day.



Water passing up a glass stem.

The rise in the level of water in the 'glass stem' is due to root-pressure.



Cross-section of a stem which has been allowed to stand in red ink. Oval portions indicate the paths by which water rises.

8. Dip the root of a plant into a bottle of red ink. After a few hours cut across the stem and you will observe that the red ink has travelled up the stem, as shown by a circle of red dots. These dots are the cut ends of the xylem up which the red ink rose.

9. To prove that a plant gives off water in the form of water vapour from its stem and leaves, take a small potted plant, envelop the pot and soil with a rubber sheet to prevent evaporation of water from them and place the whole under a bell-jar. After some time the inside of the bell-jar becomes

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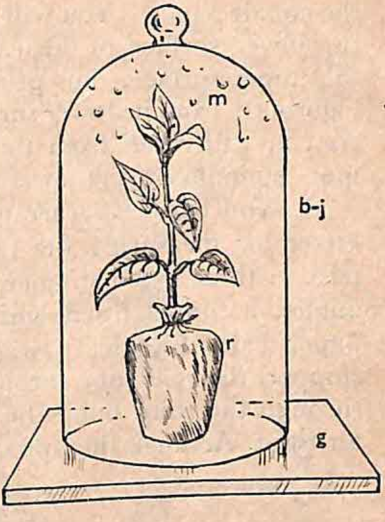
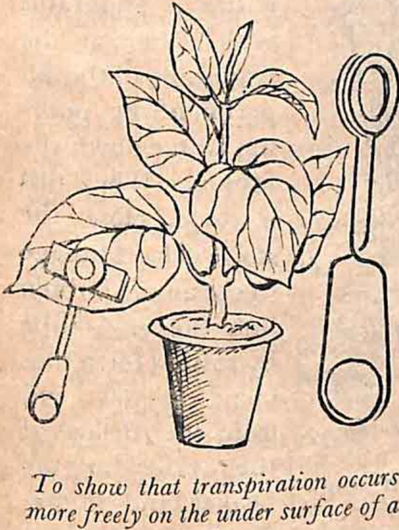
[*] In this, as in the experiments to follow, the cutting of a plant stem must always be done under water as also its connections to glass and rubber tubes. The precaution is necessary to prevent air from entering the xylem and thus breaking the continuity of the water column in the plant.

saturated with water vapour and some of the water vapour condenses and appears as tiny droplets on the inner wall of the bell-jar. Repeat the experiment having previously smeared both the upper and under surfaces of the leaves with vaseline. Try to account for any difference in the result.



To show the transpiration of a plant.
b-j, bell-jar; g, glass plate; m, drops of moisture; r, rubber sheet.

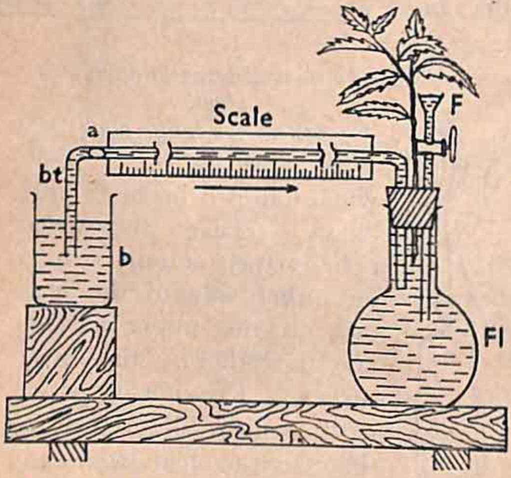
10. If you soak a piece of paper in cobalt chloride solution you will note that it becomes blue when dry, but when damp it becomes pink again. Take two dried cobalt papers and place them on either side of the leaf, one on the upper surface and the other on the lower surface. Cover each paper with a glass slide and fix them to the leaf by means of a leaf-clasp. Seal the slides to the leaf with vaseline so as to prevent moisture from the atmosphere coming into contact with



To show that transpiration occurs more freely on the under surface of a leaf.
Right: a leaf-clasp.

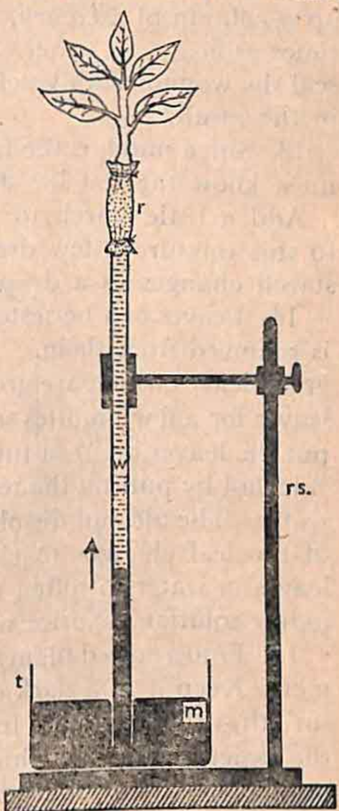
the cobalt papers. You will observe that the cobalt paper on the lower surface of the leaf becomes pink before that on the upper surface, thus proving that a leaf transpires more vigorously from its lower surface than from its upper surface. As you will recall from the text, this is because there are more stomata on the lower surface of the leaf.

11. You can easily arrange an apparatus called a potometer for measuring the rate of transpiration by using a flask, a three-holed stopper, a glass tube bent twice at right angles, a funnel fitted with a stop-cock, a beaker and a paper scale. Fit a leafy twig through one of the holes in the stopper, the bent tube through another hole and the funnel through the third hole. Be sure that these connections are air-tight. Arrange the apparatus so that the far end of the bent tube dips into the beaker. Fill the entire apparatus with water at the beginning of the experiment by pouring water down the funnel. When this is done, close the stop-cock. Manage to get an air bubble into the glass tube by raising for a moment its far end from the surface of the water in the beaker and immediately lowering it back into the water.



A simple potometer for measuring the rate of transpiration.
The arrow indicates the direction in which the air bubble moves.
a, air bubble; b, beaker; b.t., bent tube; f, funnel; fl., flask.

After some time you will notice that the air bubble in the bent tube gradually moves towards the flask. Note the time taken by the air bubble to traverse the entire length of the bent tube. Thereafter, calculate the rate of transpiration per unit time. You can send the air bubble back to the far end of the bent tube by merely opening the stop-cock and allowing water to replace that which has been lost by transpiration. This procedure will be necessary if you wish to take a set of readings to determine how different kinds of conditions, such as direct sunlight, diffused sunlight, darkness, moist air, dry air, still air and wind, affect the rate of transpiration.



To show the suction force exerted by transpiration. The arrow indicates the direction in which the column of mercury moves.
m, mercury; r, rubber tube; r.s., retort stand; t, trough; w, water.

12. Fix a woody shoot to a narrow glass tube with the aid of a length of rubber tubing and make the connections airtight. Fill the tube completely with water and after making sure that there are no air bubbles in it, dip its lower end into a dish of mercury. Support the tube and shoot by means of a retort stand. As the shoot transpires, the water lost is replaced by the water in the tube. Because of suction and the cohesive properties of liquids,

the column of water rises and pulls up a column of mercury after it. This experiment proves that the suction and other forces exerted during transpiration are great enough to pull up a column of mercury, a liquid which is nearly fourteen times as heavy as water. Strip the shoot of its leaves and seal the wounds with vaseline. Try to explain any difference in the result.

13. Since starch is the final product of photosynthesis you must know the test for starch.

Add a little starch to some water in a test tube. Add to this mixture a few drops of iodine. The colour of the starch changes to a deep blue colour.

14. Leaves can be tested for starch once the green colour is removed from them. For your experiment pluck a few green leaves which are growing in a sunny position. Boil the leaves for a few minutes so as to kill and soften them. Then put the leaves in a test tube of alcohol and gently warm the *alcohol by putting the test tube in a beaker containing hot water. The alcohol dissolves the chlorophyll and the colour of the leaf changes to either white or yellow. Wash the leaves in water to soften them again and then put them in iodine solution. Notice what happens.

15. Find a potted plant with long leaf-stalks for this experiment. Keep it in a dark cupboard overnight so as to make sure that the leaves are free from starch at the beginning of the experiment. After this period take a glass jar and pour some caustic soda solution into it. This substance has the property of absorbing carbon dioxide. Cut off a twig from the plant, place one of its leaves in the jar and fix a stopper to the jar. If there is any space between the leaf-stalk and the stopper, it can be filled with cotton-wool soaked in lime-water. Stand the entire arrangement in bright sunlight for

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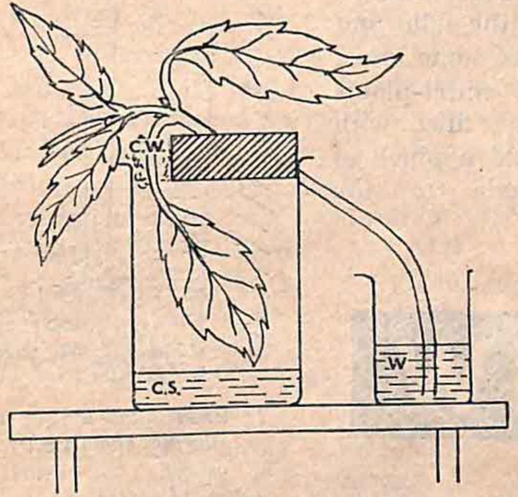
* This substance is inflammable and care must be taken not to use it in the vicinity of a flame.

about six hours and test the leaf which was imprisoned, as well as one of the other leaves, for starch. It will be found that the leaf within the jar has made no starch since it was in an atmosphere devoid of carbon dioxide which as you know is one of the raw materials from which starch is prepared. The other leaf, however, will be found to have prepared starch.

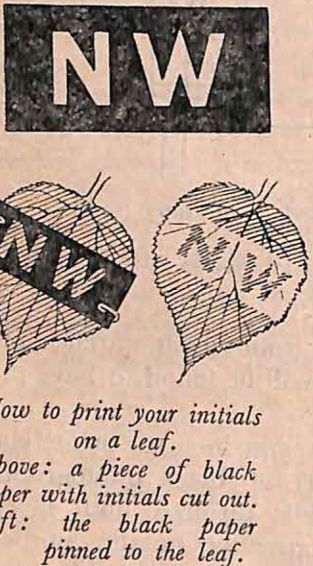


To show that carbon dioxide is necessary for photosynthesis.
c.s., caustic soda solution; c.w., cotton wool soaked in lime-water; w, water.

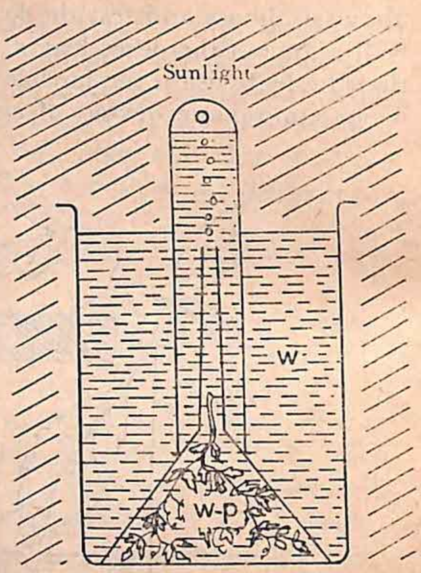
16. This experiment will show you how to 'print' your initials on a leaf. Fold a piece of black photographic paper once and cut your initials through both layers. Enclose the leaf of a plant growing in the sunlight between the layers and clip it into position with paper fasteners. Do this in the late evening. Pluck the leaf on the

following afternoon and test for starch. Can you explain the result?

17. That green plants give off a gas during starch formation can be proved in the following way. Place some green submerged water-plants in a beaker filled with water. Add a pinch of baking soda to the water.



How to print your initials on a leaf.
Above: a piece of black paper with initials cut out.
Left: the black paper pinned to the leaf.
Right: after the leaf has been tested for starch.



To show that oxygen is given off during photosynthesis.
o, oxygen; w, water containing carbon dioxide; w-p, water-plant.

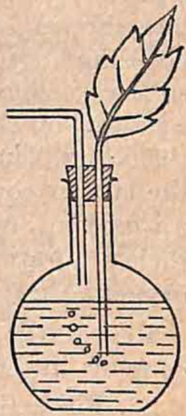
Some of the carbon dioxide produced dissolves in water and is used by the plant for starch manufacture. When the bubbling ceases, trap the water-plants under the mouth of a funnel. Invert over the funnel a test tube filled with water taking care that air does not accidentally enter the test tube and spoil your experiment. Place the apparatus in the sunlight. Bubbles of gas will be given off by the plant and will collect in the test tube. Test the gas with a glowing splinter and see if it is oxygen. Satisfy yourself by repeating the experiment with the apparatus placed in the dark. Is there a difference?

18. In the garden you will see leaves of many colours: red, yellow, purple and green. There are leaves of two colours and some even have three colours mixed together. Such leaves are called variegated leaves. As you have read, it is only green leaves that contain chlorophyll. Is chlorophyll needed for starch formation?

Pluck a leaf coloured green and yellow after it has been exposed to sunlight for several hours. Make a sketch of it, carefully copying the outlines of the green patches. Then test it for starch. You will see that only that portion of the leaf which contained chlorophyll becomes blue, showing clearly that chlorophyll is essential for the manufacture of starch.

19. Let us find out whether leaves will make starch if the stomata are kept closed. To do this, keep a potted plant in darkness for 24 hours. Smear both sides of a leaf with vaseline and expose the plant to sunlight for about six hours. Remove the vaseline and test the leaf for starch. Make sure that the result you arrive at is correct by testing one of the other leaves of the plant as well.

20. Take a glass jar and fill it with some water. Fit it with a two-holed stopper. Insert the stalk of a leaf through one hole of the stopper and through the other hole



To show the continuity of intercellular spaces in a plant.

insert one end of a bent glass tube which is connected to an air-pump. See that the cut end of the stalk dips into the water, while the end of the glass tube is just below the stopper. Make all the connections air-tight and work the air-pump. You will see that a stream of air bubbles comes out from the cut end of the leaf-stalk. This shows the continuity of intercellular spaces throughout the inside of the leaf and its stalk.

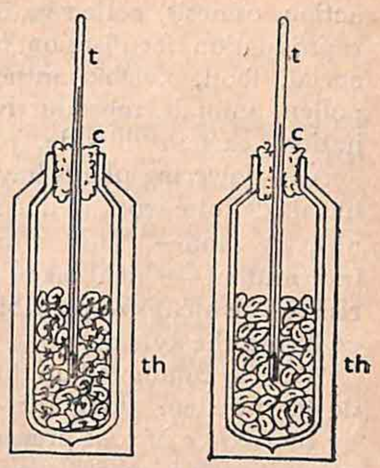
21. Take six gas jars and into each put a small test tube containing lime-water. Pour a little water into each jar. Into the first jar put nothing more, into the second put germinating seeds, into the third put flowers with their green parts removed, into the fourth put ripening fruits that are not green in colour, into the fifth put underground parts of a plant such as potatoes, onions and so on, and into the sixth put leafy twigs. Cover each jar with a greased glass plate and expose them to bright sunlight. You will notice that the lime-water becomes cloudy in all the jars except the first and last, showing the presence of carbon dioxide. Remove the covering from each jar in turn and introduce a lighted splinter. The splinter continues to burn only in the first and last jar, showing that the oxygen has been used up in all the others. The first jar served as a control experiment, while the last jar contained green leaves which, although they used up oxygen and produced carbon dioxide in the course of their respiration, also used up carbon dioxide and produced oxygen as a result of photosynthesis.

Repeat the experiment by placing the jars with their contents in darkness. Try to explain the results.

22. Fill a thermos flask with germinating seeds. Fill another with germinating seeds that have been killed by boiling and then, after they have been allowed to cool, soak them in some antiseptic such as phenol to prevent them from

decaying. Insert a thermometer in each flask so that its bulb is completely surrounded by seeds and then plug the mouth of the flask with cotton-wool. Although heat neither enters nor leaves the flask, you will see that the temperature rises in the case of the living seeds but not in the case of those that have been killed. This is due to the heat produced during the respiration of the living seeds.

23. Collect a few ripe anthers from different kinds of flowers. Shake out the pollen grains on to glass slides and examine them under a microscope.



To show that heat is given off during respiration.
The flask on the left contains germinating seeds.
The flask on the right contains dead seeds.
c, cotton wool; t, thermometer; th., thermos flask.

At home

Try to repeat at home as many as possible of the experiments mentioned under 'Laboratory work' using apparatus such as basins, tumblers, glass bottles and materials which are easily available from the kitchen or from the medicine cabinet at home.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces: root-pressure, temperature, four, transpiration, mineral salts, light, respiration, green, pulling, water, energy, soil, humidity, flower, driving, pumping action, osmosis, pollen grain, oxygen, anchors, wind, stem, reproduction, fertilisation, root, air, carbon, carbohydrates, aerial, food, xylem, anther, ovule, stigma, chloroplasts, pollen, animals, reproductive, phloem, water vapour, pollination, carbon dioxide, photosynthesis.

All—flowering plants have—parts and each of these parts has its definite work to do. The root—the plant to the—and absorbs—and—. This latter function is done by—. The intermittent—which takes place in the cells of the—gives rise to— which is responsible for forcing water from the root cells into the xylem.

Water is conducted up the—along the—and food is passed down the stem along the—. The former is done chiefly by the—force of root-pressure, and the—force due to—. By transpiration is meant the process by which the plant gives off excess water in the form of—through its—parts. The factors which affect the rate of transpiration are—,—,—, and—.

The plant has the unique capability of manufacturing its own—. This is done by—, defined as a process by which simple—are built up by the—, in the presence of sunlight, from—and water absorbed from the—and soil respectively, —being given off as a by-product. The—stored in carbohydrates is released during—. During this process oxygen unites with the—present in carbohydrates to release energy and form carbon dioxide and water.

The—is an aggregation of—structures concerned with the process of—. The transference of—from the—to the—is called—. This is effected by the wind, or by—or by water. The fusion of a—with an—is called—.

CHAPTER IX

FLOWERLESS PLANTS

IN BOOK I you read that the plant kingdom may be divided into two main divisions, the Cryptogams or 'flowerless plants' which reproduce by means of spores, and the Phanerogams or 'flowering plants' which reproduce by means of seeds. We already know something about the Phanerogams. Let us now turn our attention to the Cryptogams.

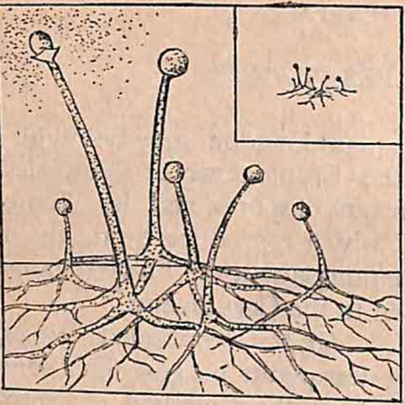
The name 'Cryptogams' (*kryptos*, concealed; *gamos*, marriage) was given to flowerless plants because for a long time very little was known about their method of reproduction.

All cryptogams are divided into two principal groups, the lower cryptogams and the higher cryptogams. Thallus plants such as the Fungi are included among the former while the Mosses and Ferns constitute the latter group.

Fungi: Mould and Yeast. The plants grouped together under the name of fungi are most peculiar and unlike any of which you have read. Here you will read of plants that have no stems, leaves, roots or flowers. Since they lack chlorophyll they are unable to make their own food and are forced to take it ready-made from dead or living things.

Among the commonest members of the fungi family are the Moulds. In wet weather they are found covering almost anything, from old shoes to stale bread. The conditions they need to thrive in are dampness and darkness.

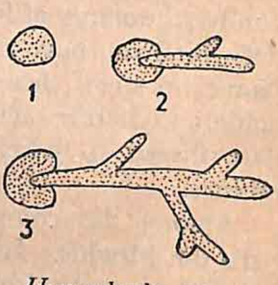
Place a piece of moist bread in a dark corner of a cupboard. Inspect it from time to time. Within a few days, mould will appear like a covering of down. Look at the mould through a powerful magnifying glass. You will see a forest of fine, shiny, white threads weaving in and



A growth of mould.
Inset: actual size of a mould.

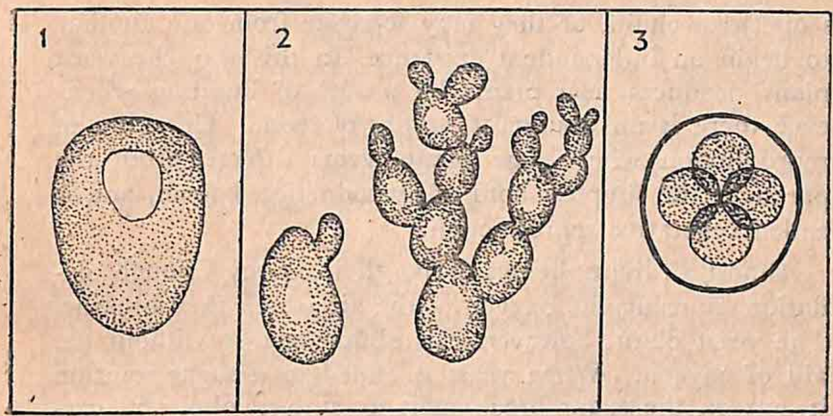
out of the bread. Each thread consists of colourless cells set end on end. It is known as a hypha. A collection of threads is called a mycelium. Soon the mould becomes dotted with tiny pearl-like spore cases. A case, called a sporangia, is as small as the head of a pin and contains an immense number of spores. As the head ripens it becomes black and finally bursts delivering its contents to the wind.

A spore corresponds to the seed of a flowering plant. It is as fine as a dust particle. The air is normally filled with the spores of moulds and other fungi. If conditions are right, a spore starts to grow the moment it settles and gives rise to a fresh growth of mould. Reproduction by means of spores is asexual reproduction.



How a hypha grows out of a spore. (Highly magnified.)

Yeast is another example of a fungus. It is used by the baker for making bread. Obtain some yeast from the baker and examine it. You will see that it appears to be a fine light-brown powder. View a small quantity of this powder under a microscope. You will now see that the powder actually consists of a large number of separate cells. Each cell is a yeast plant. In the centre of the cell you will see that there is a small cavity.

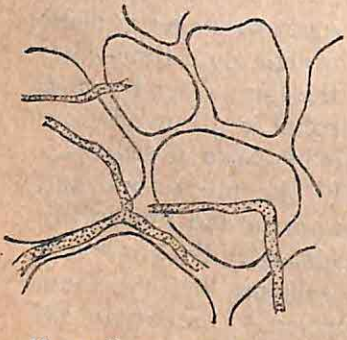


The yeast plant.
(Highly magnified.)
1. *A single plant.* 2. *A plant reproducing by 'budding'.* 3. *A plant reproducing by means of spores.*

If you put some yeast into a solution of sugar you will observe that bubbling occurs. Obviously some gas is being given off. On passing this gas through some lime-water it is seen to be carbon dioxide, for the lime-water becomes milky. A characteristic smell of alcohol is given off from the sugar solution to which the yeast has been added. Examine a drop of this solution under the microscope and you will observe that the plant has grown and multiplied. Small swellings may be seen on each cell. Each swelling constitutes a new cell. These new cells gradually increase in size until each new cell is connected to its parent cell by a narrow neck. Thereafter, a cell wall grows across the neck to separate the new cell from its parent cell. The cell may remain united and in the same way produce a series of new cells which appear under the microscope as a chain, or they may separate from one another to begin an independent existence. In this way the yeast plant produces new plants by a sort of budding whenever there is an abundant supply of food. This kind of reproduction where new plants grow directly from the parent is the simplest kind of reproduction known, and is called vegetative reproduction.

Almost all living beings derive their energy through oxidation by using the oxygen of the air which they breathe. The yeast plant, however, can obtain energy without the aid of oxygen. When yeast is added to a sugar solution it acts on the sugar breaking it up into alcohol and carbon dioxide, and during the process, liberates energy in the form of heat. The process by which this is done is called fermentation.

If the yeast plant is starved, the protoplasm in its cell divides into four parts and a cell wall grows around each part so that four spores are formed. These spores escape into the air. When again they find suitable conditions they give rise to ordinary yeast cells. This method of reproduction is another example of asexual reproduction.



How cells are attacked by a fungus.
(Highly magnified.)

The majority of the fungi are the villains of the plant world. Certain kinds of fungi similar to moulds, such as mildews, rusts, blights and smuts, ruin our grain and food crops. The farmer wages a never-ending battle against these pests, protecting his plants by spraying and dusting them with chemicals. Moulds attack men and animals as well. You will be surprised to know that ringworm is caused by a mould and so also is the mange on a dog. Water is no barrier to the spore of a mould and many a goldfish in an aquarium suffers an attack. Caterpillars, house-flies, wasps and water-beetles all fall victim to the parasitic moulds.

Not all the moulds, however, are bad. Some of them play an important and useful purpose in the plan of life. Certain moulds live on the stumps of dead trees and feed on the remaining food material until the stump crumbles and becomes part of the soil. They thus hasten decay and prevent our forests from becoming choked by dead plants. There is a large number of other moulds that feed on plant and animal rubbish causing decay to take place more quickly.

Yeast has been used from early times to make alcoholic liquids, such as beers, wines and spirits. It is used in the making of bread. The carbon dioxide produced by the yeast puffs out the dough and blows holes in it thus making the bread spongy, light and more easily digestible. The alcohol produced at the same time evaporates.

In Europe, cheese-makers add certain moulds to cheese to give it a delicious flavour.

Scientists have discovered how to make use of a certain kind of mould to destroy insects that harm valuable plants. Some of these insects are first captured and treated with the mould. They are then set free and allowed to join their companions. When they mix with their fellows the mould disease spreads. In course of time a good number of the insects die of the disease.

Recently it was discovered that substances called penicillin and streptomycin can be obtained from certain kinds of moulds. These discoveries brought new hope to the suffering. Today penicillin and streptomycin are used by doctors all over the world and have saved countless from dying of horrible diseases.

Mosses. These plants are commonly seen during the monsoon on old damp walls, by the banks of streams and in woods where there is plenty of shade and moisture. A large number of them grow close together forming, to the eyes of a casual observer, a soft velvet-like green carpet.

A moss.

Mosses are simple plants which have tiny, leaf-like parts growing out from very thin stem-like organs. They are fixed to the soil by strands called rhizoids which grow from the lower end of their stalks. Although rhizoids are not true roots, they do the same work that roots do, that is, they fix the plants to the soil and absorb water and mineral salts from it.

In the life-history of mosses there are two stages or generations. One generation called the sporophytic generation reproduces asexually by means of spores and the next generation called the gametophytic generation reproduces sexually by means of male cells called spermatozoids and female cells called *ova. Each generation gives rise to the other, that is the sporophytic generation gives rise to the gametophytic generation which in turn gives rise to the sporophytic generation and so on. This regular alternation of the sporophytic generation with the gametophytic generation is called alternation of generations.

At certain seasons the moss plant (the gametophyte) bears male organs which produce spermatozoids equipped

*Ova is the plural form of ovum.

with two tails and female organs which contain ova. These organs are borne either together at the apex of the same shoot or separately at the apexes of two branches of the same plant or at the apexes of the shoots of two separate plants. After a heavy fall of rain the place being flooded, the spermatozoids swim by means of their tails to the female organs and fertilize the ova. A fertilized ovum thus formed grows into a tiny new plant (the sporophyte) which lives long enough to produce a stalk at the end of which is a tiny capsule. In the capsule microscopic spores are developed. In due course the capsule opens by means of a lid and liberates the spores which fall on the ground. If conditions are favourable the spores germinate putting out hair-like threads which ramify in the soil and ultimately develop into moss plants.

Moss plants help to build up soil on rocks. When those plants that are growing on a rock die, their decaying remains accumulate in the crevices of the rock, mix with the dust and crumbling rock particles that are already there, and form a few grains of soil. As more moss accumulates, the soil becomes richer and holds more moisture. After some years, larger plants are able to grow on the rock and take their nourishment from the soil thus formed.

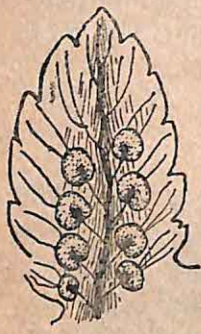
Ferns. Like mosses, these plants also prefer to grow in

A fern.

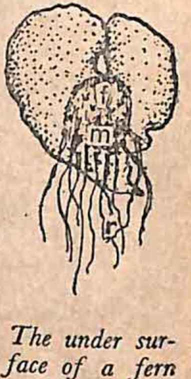
cool, shady, moist places. They are the most highly developed of the flowerless plants. They resemble a flowering plant in nearly all respects except in their way of reproduction.

The stem of the fern grows more or less horizontally under the surface of the ground, giving off many adventitious roots from its under surface. The leaves, called fronds, are compound and are borne on the upper surface of the stem. The fronds push their way from the soil into the air. Young leaves are coiled and covered with small brown scales. As they grow older they unfold towards the growing region of the stem.

If you look at the under surface of the leaflets of a fern you are likely to see many greenish-brown, kidney-shaped knobs called sori. These contain spores. In the summer, spores are ejected from the sori. Under favourable conditions a spore germinates not into a fern, but into a tiny, flat, heart-shaped structure called a prothallus. This plant grows rhizoids and bears male and female sex-organs on its under surface. The male organs produce spermatozoids each equipped with several tails which enable them to swim in wet weather to the female organs in which are contained ova. The sperms enter the female organs and fertilise the ova. A fertilised ovum remains within the prothallus and grows into the ordinary fern, which in turn, produces spores.



A portion of the under surface of a fern leaf showing sori.



The under surface of a fern prothallus. f, female organs; m, male organs; r, rhizoids.

There is thus in the fern, as in the moss, an alternation of generations. In the fern, however, the sporophytic generation (the fern plant) is more prominent than the gametophytic generation (the prothallus).

Ferns are valued for their beautiful foliage and are therefore usually grown in gardens. Apart from being grown for ornamental purposes, they are of little use to man.

CHAPTER ACTIVITIES

Outdoors

1. Visit the baker and see how he uses yeast to make bread rise.
2. Visit a brewery and see how yeast is used to make alcohol.
3. Find and examine (*a*) a moss plant, (*b*) the capsule of a moss plant, (*c*) a fern plant, (*d*) the sori of a fern plant, (*e*) a prothallus.

For your wall newspaper

1. Plan and prepare a chart to show the alternation of generations in the fern plant.
2. Make a large drawing of a moss plant. Label its various parts. Draw a line through the plant separating the gametophyte from the sporophyte.

Note-book exercises

1. Write a note on the commercial importance of yeast, describing in detail the part it plays in bread-making and in the preparation of alcohol.
2. Compare a moss plant with a rose plant. Say how they are different and how they are alike.
3. Write a summary of this chapter.

Laboratory work

Plan and perform an experiment to test the fact that carbon dioxide is given off when yeast is added to sugar solution.

At home

1. Spores of mould plants are everywhere, riding on the wind. Try to catch some and grow them. This is how to do it. Place some cheese, leather, jam and bread in separate saucers. Keep them in a warm dark place. Moisten the pieces of bread, leather and cheese regularly. Within a few days different kinds of moulds should make their appearance. Record the number of hours they take to form sporangia. Then place the moulds in the sunshine and see what results.

2. Are there spores present in dust? Gather some dust on the tip of a feather and sprinkle it on a bit of bread. Moisten the bread and cover it over with a tumbler. Let it remain for a while in the dark. From this dust a garden of mould will grow.

3. Attempt to germinate the spores of a fern plant on a piece of unglazed earthenware. While the spores are germinating it will be necessary to keep the earthenware moist and in the shade.

Chapter X

THE CELL: SINGLE-CELLED ANIMALS

With the invention of the microscope, scientists began to explore a new world, a world which had remained invisible up to then. Whenever they studied living things under the microscope they found 'cells'. Some kinds of plants and animals were found to consist of only one cell, but the majority of living things were made up of billions of cells living together, each co-ordinating its activities with that of the others for the benefit of the living thing.

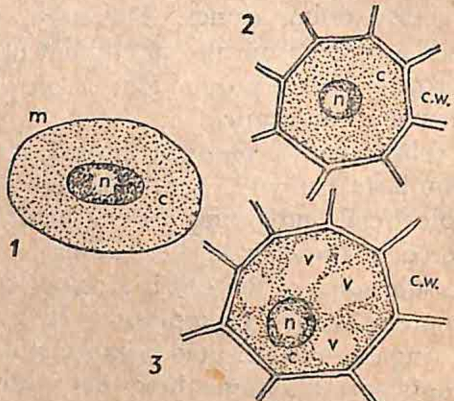
Cells. Cells may be regarded as the basic units of the organisation of all living things. They make up the body of a living thing in very much the same way as bricks make up the walls of a building. Unlike bricks, however, cells are alive and continuously doing things. Therefore, whenever we consider a living thing from the standpoint of its structure, functions, growth and reproduction, a knowledge of the cell is of primary importance.

Since all cells, whether plant or animal, are constructed somewhat similarly, we will confine ourselves to a description of a typical cell, indicating those structures which may be encountered in the cells of most things.

The basic substance of the cell is a colourless, semi-fluid, gelatinous material called protoplasm. It is a living substance consisting of a complicated mixture of substances. In fact it is the only part of a living thing that is alive, for all the rest is dead material produced by the activity of the protoplasm. The protoplasm of any particular cell is different both chemically and physically in different living things. Furthermore, it constantly changes its physical and chemical state according to the activities of the living thing. It possesses the power of movement. Its movement can be observed in cells which have thin walls, especially when there are a number of granules in it.

Although scientists know what protoplasm in a dead cell is made of, no one has yet succeeded in making it. Living things alone can make this substance from the food digested in their bodies.

Protoplasm is differentiated into two portions in each cell. The bulk of it is called the cytoplasm while the other part of the protoplasm which is denser is the nucleus. The nucleus is spherical in shape and usually lies near the centre of the cell. It is separated from the cytoplasm by a membrane called the nuclear membrane. The most important part of the cell is the nucleus for it seems to control the life and growth of the cell. The outer surface layer of the cytoplasm is known as the plasma membrane. It is very thin and delicate



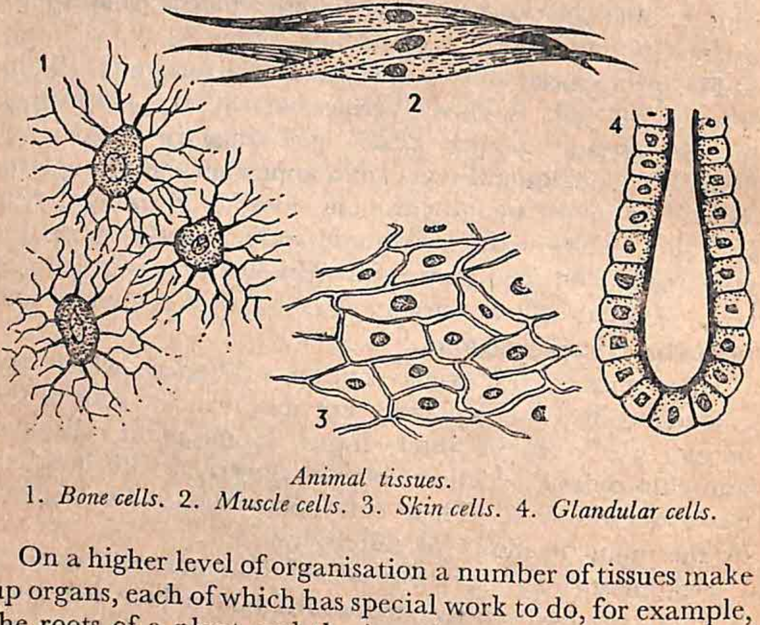
Cells.
1. *An animal cell.* 2. *A young plant cell.* 3. *An old plant cell.*
c, cytoplasm; c.w., cell wall; m, cell membrane; n, nucleus; v, vacuole.

and serves to hold the contents of the cell and to regulate the passage of materials into and out of the cell. In the cells of most plants there is a cell wall made up of a substance called cellulose. This substance is secreted by the protoplasm of the cell and is dead material. In comparison with the plasma membrane it is porous and does not in any way interfere with the exchange of materials into and out of the cell. Animal cells lack a cell wall and cellulose is not found in any animal's body.

The protoplasm of a young plant cell occupies all the space in the cell. As the cell grows older it increases in size, but the amount of protoplasm contained in it does not increase. Consequently, vacuoles appear in the protoplasm which gradually merge into one another forming larger vacuoles. These vacuoles contain water together with dissolved salts and food materials. This solution is called cell sap. Animal cells are nearly always full of cytoplasm and never have large vacuoles.

Sometimes certain cells contain substances which are embedded in the cytoplasm. For instance, the cells of the potato tuber contain starch grains. Some plant cells contain chloroplasts which are bodies concerned with building up food substances. These chloroplasts are coloured green by the pigment known as chlorophyll.

Protoplasm can carry out all the fundamental functions of living things, such as moving, feeling, feeding, respiring, excreting (getting rid of waste products), growing and reproducing. Animals and plants composed of just a single cell can carry out all these functions, but in the case of living things composed of millions of cells there is specialisation. Certain cells perform just one special function. Such a collection of cells, congregated into a group and doing the same work is called a tissue. There is thus division of labour among the cells of a living thing. The shape and structure of the cells comprising a tissue are the same and specially suited for their particular activity. Examples of tissues in the human body are muscle cells, bone cells and blood cells. The life of the cells comprising a particular tissue is to a large extent dependent upon the activities of the cells comprising other tissues and dies if separated from them.

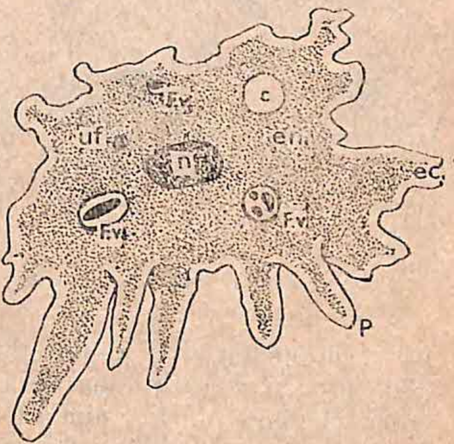


Animal tissues.
1. *Bone cells.* 2. *Muscle cells.* 3. *Skin cells.* 4. *Glandular cells.*

On a higher level of organisation a number of tissues make up organs, each of which has special work to do, for example, the roots of a plant and the intestines of an animal. On a still higher level of organisation, a number of organs are arranged into systems which carry out correspondingly larger functions for the plant or animal. In the human body, for example, there is the digestive system, the circulatory system and so on. Finally, a group of co-ordinated systems climaxes the series of successively higher levels of organisation to make up the individual living thing.

Protozoa. This is a group of the animal kingdom in which the lowest and simplest animals are placed. These animals consisting of one cell are microscopic in size. Although so small it is remarkable that, within the confines of a single cell, the animal carries on all the life processes as animals whose bodies are made up of billions of cells. The amoeba and paramecium are taken here as representative of the group.

Amoeba. The amoeba is usually found on the mud of fresh water of ponds and sluggish streams. When examined under the microscope the amoeba is seen to be no more than a single, minute bluish-grey blob of protoplasm. Two distinct zones can be distinguished in the animal. The outer protoplasm, called ectoplasm, is clearer than the inner granular protoplasm, which is called the endoplasm. Almost in the centre of the endoplasm the nucleus is embedded.



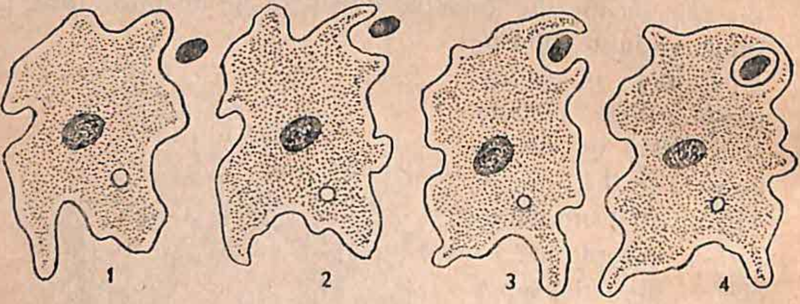
An amoeba.

c, contractile vacuole; ec., ectoplasm; en., endoplasm; f.v., food vacuole; n, nucleus; p, pseudopodium; u.f., undigested food.

The amoeba changes its shape frequently. At certain points of its surface it pushes out blunt, unbranched, finger-like projections of its protoplasm called pseudopodia, which means false feet, while at other points it draws its protoplasm inwards. By changing its shape in this way it propels itself through the water with a sort of 'rolling over' motion.

The amoeba is sensitive to external stimuli. It contracts in bright light and moves away to wherever the light is less. Heat and certain chemical substances cause the amoeba to behave in a similar manner. If an electric shock is passed through the water in which it lives, it immediately withdraws its pseudopodia.

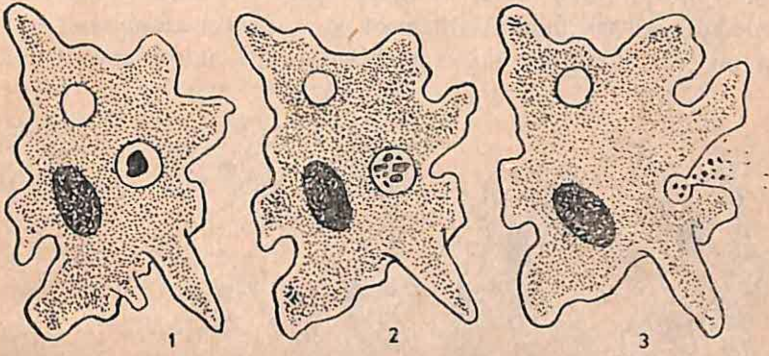
The food of the amoeba consists of microscopic water-plants. When the animal meets a food particle on its journey, its pseudopodia flow round the particle and engulf it. This process is called ingestion. When the food particle enters the body of the animal it is enclosed with a drop of water in the endoplasm. The space occupied by the food particle and water is called a food vacuole. Digestion now takes place. The food particle is gradually dissolved by the action of an acid made by the endoplasm and finally broken down by digestive fluids into substances from which protoplasm can be built up. At the end of the process the liquid contained in the food vacuole becomes alkaline, and thereafter diffuses into the endoplasm which assimilates it. The solid indigestible parts that remain in the vacuole are cast out and left behind as the amoeba moves on. The



To show how an amoeba ingests its food and forms a food vacuole.

process of expelling unused parts of the food from the animal's body is called egestion.

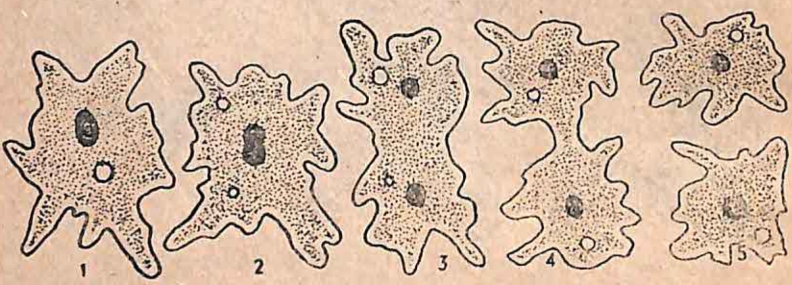
For the purpose of respiration the amoeba absorbs oxygen dissolved in the water by diffusion through its surface. The oxygen absorbed is used to oxidise some of the protoplasm and thus produce the energy required by the animal to perform its life activities. As a result of the oxidation, waste products such as carbon dioxide, water and a substance called urea are formed. Carbon dioxide formed during respiration is passed out into the surrounding water through the surface of the amoeba.



To show how an amoeba digests its food and eliminates waste matter.
1. *An amoeba just after food has been ingested.*
2. *An amoeba while food is being digested.*
3. *An amoeba during the process of egestion.*

Other waste products formed during respiration are removed from the amoeba's body by the contractile vacuole. This vacuole forms in the endoplasm and becomes larger as water accumulates in it. Ultimately when a certain limit of size is reached by the vacuole it is brought close to the surface of the body where it contracts to expel its contents into the surrounding medium. Thereafter it begins to re-form again and in due course repeats the process of excretion.

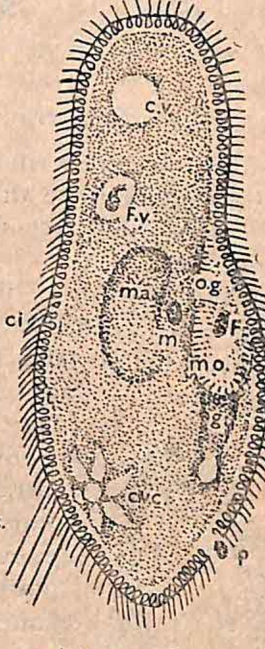
When the amoeba has grown to a certain size it divides into two. First, the nucleus divides by contraction into two equal daughter nuclei, which move apart. Next the protoplasm narrows between the nuclei and gradually divides into two separate parts, each part containing one of the daughter nuclei. Each of these parts is a young amoeba, bearing all the potentialities of the original amoeba. Such a process of reproduction is called simple or binary fission.



To show how an amoeba reproduces by binary fission.

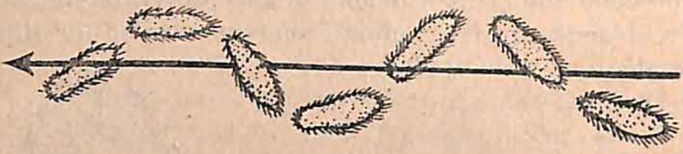
In periods of adverse conditions such as long periods of cold or drought (the latter occurs when the pond dries up) the amoeba withdraws its pseudopodia, becomes spherical and secretes around itself a thick, resistant wall called a cyst. In this condition it passes through a resting state and since it cannot obtain food it lives on its own protoplasm. When favourable conditions return, the cyst bursts and the animal flows away from its self-made prison to resume its normal life. Sometimes, however, while in the resting state the nucleus and protoplasm divide many times with the result that when favourable circumstances return, a number of young amoebae with pointed pseudopodia, called spores, make their escape. Such a process of reproduction is called multiple fission or spore formation. Both simple and multiple fission come under the category of asexual reproduction.

Paramecium. This animal, sometimes called the slipper animalcule, is a small elongated slipper-shaped animal that lives in fresh-water pools. When examined under the microscope it is seen that its body is covered by a tough, yet flexible membrane called the pellicle. It, therefore, has a definite shape. The entire body of the animal is covered with fine hair-like threads called cilia. Paramecium is driven through the water by the rhythmic movement of its cilia which propel the animal forward like a boat moved by oars. Since the cilia are arranged in the form of a spiral down the longitudinal axis of its body, when the animal swims, it revolves through the water following a spiral course. Paramecium always moves with the blunt end of the slipper forward.



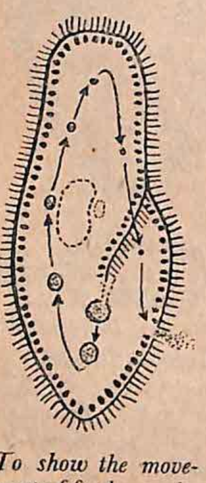
A paramecium.
ci., cilia; c.v., contractile vacuole (expanded); c.v.c., contractile vacuole (contracted); d.t., discharged trichocysts; f, food particle; f.v., food vacuole; g, gullet; m, micronucleus; ma., macronucleus; mo., mouth; o.g., oral groove; p, pore for ejection of waste matter; t, trichocysts.

Tiny bulbs shaped like spindles, called trichocysts, are embedded in the pellicle. They are filled with a gelatinous material. When irritated, the animal suddenly squirts out this liquid into the water. On contact with the water the liquid hardens to form sticky threads. Enemies of the animal are rendered harmless when they get entangled in these threads. By means of these threads the animal also anchors itself. It breaks itself free from the threads when it wishes to move on.



To show the spiral path taken by paramecium.

The underside of the animal, called the ventral side is always flattened. On this side is a groove called the oral groove which extends from the anterior end of its body to a slit-like mouth found a little below the middle of the body. The groove opens to the interior of the body by means of a gullet. Cilia are arranged all along the groove. Water currents are set in motion towards the mouth by the vibration of these cilia. Particles of food such as one-celled animals and plants, including bacteria, are swept towards the animal with the water currents.



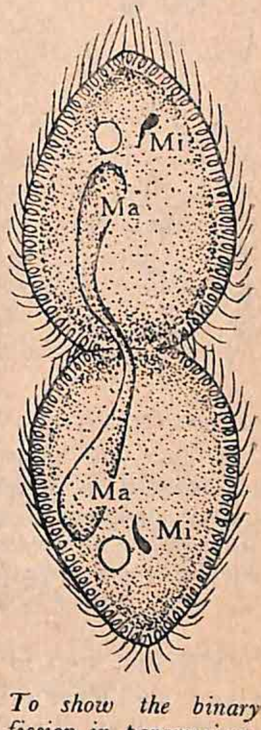
To show the movement of food vacuoles in paramecium.

Food passing down the gullet is rounded up into food vacuoles, they then break free from the gullet and slowly move round the body in a definite circuit due to the streaming movement of the cytoplasm. Here, as in the amoeba, an acid fluid is first secreted by the cytoplasm into the vacuole, followed by an alkaline fluid. These fluids bring about digestion. After the food has been made soluble it diffuses into the cytoplasm which assimilates it. By the time a food vacuole has completed a single circuit it only contains undigested remains and has shrunk in size. At the end of the circuit it reaches an opening called the anal pore which lies immediately below the gullet. Undigested materials are now expelled through this opening.

As in the amoeba, respiration in the paramecium is carried on by the diffusion of oxygen dissolved in the water through the surface of the animal. Carbon dioxide diffuses out of the animal's body, while water is ejected by means of the contractile vacuoles.

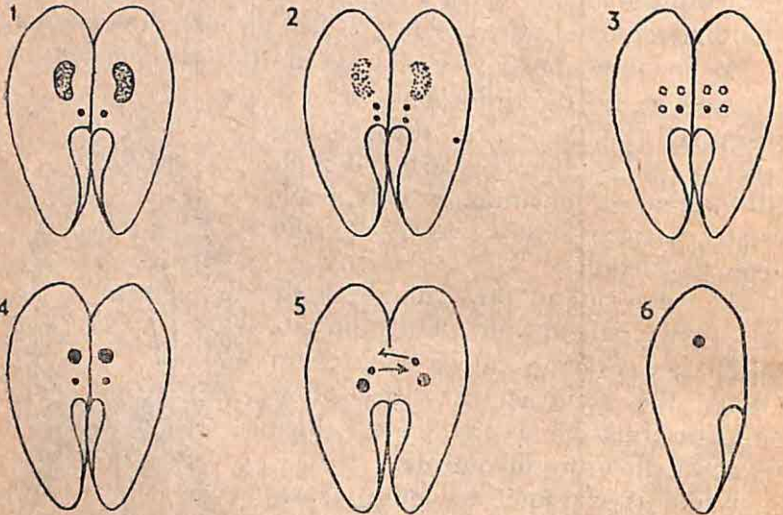
At each end of the animal's body is a contractile vacuole. These pulsate alternately every twenty seconds or so. When they contract they eject their contents through a small pore which connects them to the outside.

While the animal is young it reproduces asexually by simply dividing into two, that is, by binary fission. Although composed of a single cell, paramecium possesses two nuclei, a larger one called a macronucleus and a smaller one called a micronucleus. During asexual reproduction there is a division of each of the nuclei. Asexual reproduction takes place about once every ten hours. The rate, however, slows down with the accumula-



To show the binary fission in paramecium. Ma., macronucleus; Mi., micronucleus.

tion of waste products in the water, lack of food and unsuitable temperatures. As asexual reproduction continues for a number of generations the individuals become weaker. Furthermore, adverse environmental conditions also cause the animal to weaken. Conjugation, a kind of sexual reproduction, now occurs.



To show conjugation in paramecium.
1. Union of two paramecia. 2. *Beginning of division of micronuclei and disintegration of macronuclei.* 3. *Redivision of micronuclei and disintegration of three in each paramecium.* 4. *Division of micronuclei into small and large portions.* 5. *Exchange of the smaller portions.* 6. *A paramecium after conjugation.*

The first step to conjugation is seen when two animals come together and become joined at their oral grooves. The micronucleus of each animal divides twice while the macronucleus disintegrates as it is only concerned with the life activities of the animal and not with reproduction. Out of the four micronuclei in each animal, three disintegrate. In each animal the remaining nuclei divide into a smaller portion and a larger portion. The smaller portions then move from one animal to the other by way of a protoplasmic bridge and unite with the larger portions in the other animal. Thereafter the two animals separate. Up to this point there has been no reproduction. Each animal contains, however, a nucleus which is partly composed of its own substance and partly that from the other animal. Thereafter each divides and re-divides into four animals.

Chapter Activities

Outdoors

You will never know much about living things unless you go outdoors in all seasons and at all hours to study them. Under 'Laboratory work' you will be studying many tiny animals under the microscope. In order to collect these animals you must go to the nearest pond or stream and collect them in test tubes as outlined.

For your wall newspaper

1. Plan and prepare a chart to show how cells make tissues, tissues make organs and organs make organ systems.
2. Make labelled drawings of the sections and creatures you examine in the laboratory and mount the drawings on your board.

Note-book exercise

Compare the amoeba with paramecium. In what ways are paramecia more advanced than the amoeba?

Laboratory work

1. Cut sections of the roots and stems of a herbaceous

plant by cutting each crosswise with a safety razor-blade. Put each section in a drop of water on a glass slide. Lay a cover slip over it so as to keep it moist and flat. This should be done very carefully so as to eliminate air bubbles. Liquid around the cover slip should be absorbed with blotting paper. Place each slide under a microscope and examine it.

2. Cut sections from a cork and soak each section in a watch-glass containing iodine solution. Thereafter, wash each section by soaking it for some time in a watch-glass containing water. Mount each section on a glass slide and examine it under the microscope. You will observe that the cells being dead have lost their contents and that the walls of the cells have been stained yellow by the iodine solution.

3. Peel a very thin layer from the scale of an onion bulb. Mount it on a glass slide and examine it under the microscope.

4. Use a clean, sharp razor-blade to gently scrape a little matter from the inner surface of your lip. Mount it on a glass slide and examine it under a microscope.

5. Obtain prepared slides of animal and plant tissue and examine each under the microscope.

6. Observe the continuous current of protoplasm in a cell by mounting a young leaf of a moss plant under the microscope and examining it.

7. Examine a drop of pond water under the microscope. You will be amazed at the number and variety of protozoa and other minute varieties of plant and animal life that can be seen.

8. Skim off the surface, mud from the bottom of a sluggish stream with a wide test tube. Allow the muddy water to settle in the test tube for a day. Obtain a sample of the

water by means of a pipette. Put this sample in a watch-glass placed on a sheet of black paper. Amoebae in the sample of water will be seen as greyish specks. Use the pipette again to transfer an amoeba from the watch-glass to a glass slide and then examine the amoeba under the microscope. Observe its movement. Sketch it every minute and in this way obtain a series of drawings to show the changes of shape it undergoes.

9. Kill an amoeba by introducing a few drops of weak acetic acid under the cover slip. Besides killing the animal this acid also stains the nucleus which now stands out clearly.

10. Boil a handful of hay and several wheat grains in a beaker of water. Allow the contents of the beaker to stand for about five days and then add a little water from a pond. The protozoa in the pond water will grow and multiply on the food you have supplied. After a further period of five days you will probably see paramecia moving about in the water as white specks. Transfer a paramecium from the beaker to a glass slide and examine it under the microscope.

11. Digestion in the paramecium can be observed by placing some yeast cells stained with congo red on a slide together with a paramecium. Observe the process under the microscope.

12. Paramecium can be killed and stained at the same time by introducing under a cover slip a drop of a stain called methyl green dissolved in acetic acid. Examine it under the microscope after this is done.

At home

If you own a powerful magnifying glass you can study a few of the microscopic creatures that abound in a pond.

Try to identify some of the creatures you see with the help of a college text-book on Biology.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces: simple, oral groove, amoeba, protoplasm, carbon dioxide, cells, oxygen, surface, mouth, organ, cilia, gullet, water, complex, nucleus, two, tissue, director, heat, conjugation, multiple fission, food, paramecium, system, pseudopodia, plasma membrane, light, protozoa, trichocysts, cytoplasm, chemical substances, contractile vacuole, one-celled.

Every living thing is composed of tiny living units called —. A typical living cell contains—which is differentiated into the—and the—. The surface layer of the cytoplasm is called the—. The nucleus may be described as the—of the cell's activities. A group of similar cells performing a particular function is called a—. Different kinds of tissues make up an—. A number of organs are combined in a group to form a—. Simple—living things carry out their vital life processes without any specialised organ systems; but larger more—living things have various organ systems to perform their various life functions.

The—and—are one-celled animals belonging to a class of animals called the—.

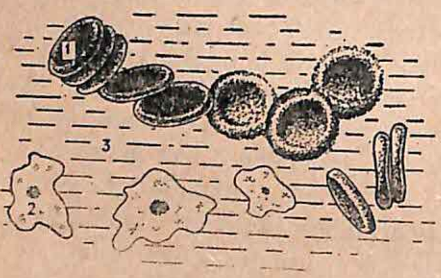
The amoeba moves by the formation of —round the edges of its body. It is sensitive to—, —and—which might injure it. It obtains its—by merely wrapping itself around a food particle. —is absorbed from the water and—passes out of its body through its surface. It rids itself of waste products by means of a—. It reproduces by simple and—.

The paramecium moves by means of—. All over the surface of its body it has—which help to protect it from enemies. It has a primitive 'digestive system' consisting of a—, an—and a—. Oxygen is absorbed from the—and carbon dioxide passes out of its body through its—. Water is got rid off by—contractile vacuoles. It reproduces by—fission and by—.

OUR AMAZING CIRCULATORY SYSTEM

Within each one of us is the most remarkable transport system in the world. It consists chiefly of a central pump and a system of pipes through which blood is pumped. Silently and automatically, working day and night, it ventilates, supplies food and removes waste. Press the fingers of one hand on the inner part of the wrist of your other hand below the base of the thumb and you feel the blood surging through one of the highways of the system.

The Blood. If a drop of blood is examined under a powerful microscope it will be seen that it is not the sticky, red liquid it appears to be. Actually it consists of a pale, yellow liquid called plasma, in which float millions of living cells. Certain types of these cells, called corpuscles, are of two kinds: red corpuscles and white corpuscles.

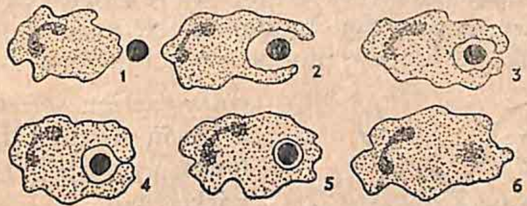


Blood corpuscles.
(Highly magnified.)
1. *Red corpuscles.* 2. *White corpuscles.*
3. *Plasma.*

The Red Corpuscles. These are minute discs thinner at the middle than at the edges. They contain a chemical which is red in colour called haemoglobin. The enormous number of these corpuscles in the blood make it appear to be red in colour.

Haemoglobin is capable of uniting with oxygen and transporting it from the lungs to all parts of the body. When combined with oxygen, haemoglobin is bright red in colour, but when it has given up its oxygen its colour changes to dark red.

White Corpuscles. Although large numbers of white corpuscles are present in the blood they are less numerous than the red. They are colourless and vary both in size and form. The white corpuscles constantly change their shape and are capable of movement. Their work is to destroy disease germs that find their way into our bodies. They do this by throwing out arms which close around the germs. Having captured them in this manner, they proceed to digest them. They are not always successful in their efforts and are sometimes killed by the germs instead. When this happens, illness may result.

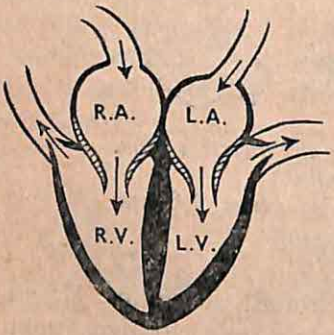


How a white corpuscle catches and digests a germ. (Highly magnified.)
1-3, *a white corpuscle approaching a germ;* 4-6, *how the germ is digested.*

The Plasma. About 90 per cent of the plasma is water in which several important substances are contained in solution. Digested food absorbed by the small intestine passes into the blood and is then transported to all parts of the body by the plasma. Wastes from all the cells of the body also pass into the plasma and are carried to places such as the lungs and the kidneys where they are finally got rid off.

One of the substances dissolved in the plasma is a protein called fibrinogen. When any part of the body is cut, bleeding results. White corpuscles immediately rush to the spot to attack any germs which attempt to enter the wound. Those that die in defending the body, together with the germs that also die in the battle, form 'pus'. Meanwhile the blood cells that were damaged when the cut was made mix with the fibrinogen to form an insoluble substance. This substance forms a cottony network of fibres across the wound to make a solid clot of blood that seals off the wound and prevents further loss of blood. Red corpuscles entangled in the threads give the clot its red colour.

The Heart. Blood is pumped round the body by the muscular action of the heart. It lies in the chest between the lungs and is about the size of a cricket ball.



Diagrammatic section of the heart to show the chambers and the direction of blood flow.
R.A., right auricle;
L.A., left auricle;
R.V., right ventricle;
L.V., left ventricle.

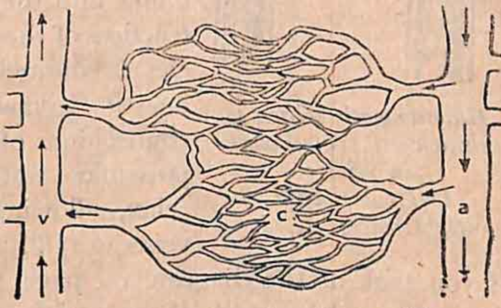
If the heart is cut open it will be seen to consist of four chambers. There is no communication between the chambers on the right and those on the left. The two upper chambers are called auricles, and the two lower chambers are called ventricles.

Between the auricle and the ventricle on each side of the heart and also between each ventricle and the tube that leads away from it is a valve. These valves allow blood to flow in only one direction.

Arteries, Veins and Capillaries. There are three kinds of tubes which transport blood around the body. These are the arteries, veins, and capillaries. Arteries carry blood away from the heart while veins bring blood back to the heart. Capillaries connect arteries to veins.

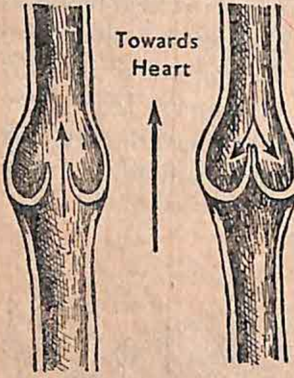
The arteries have strong, tough, elastic and muscular walls. They do not collapse when empty. The elasticity of their walls enables them to increase in diameter when blood is forced into them, and the muscles in their walls help the heart to force blood along. Each of the main arteries that leave the heart is almost an inch in diameter. They grow progressively smaller, the further they are from the heart, and finally, after repeatedly dividing and sub-dividing, they give rise to the capillaries.

The great network of capillaries is a very important part of the circulatory system. They are fine, hair-like tubes with very thin walls. The diameters of these tubes are so small that red blood corpuscles can only pass through them in single file.



Diagrammatic section of artery (a), capillaries (c), and vein (v).

The capillaries gradually link up again forming larger and larger veins which in turn open into the great veins leading back to the heart. The walls of the veins are similar in structure to the arteries, except that they are much thinner and not nearly as elastic or muscular. On account of this, veins collapse when empty. In many veins there are valves which allow blood to flow only in the direction of the heart. These valves are most abundant in those veins which pass along the arms and legs. If you hang your arms by your sides you will make the blood flow backwards on the valves, thus causing the veins to fill out and present a knotted appearance.



Diagrammatic section to show how the valves work in veins.
Left: valves open.
Right: valves closed.

Circulation of the Blood. You have already read that blood is circulated throughout the body by the muscular action of the heart. When the auricles are full of blood, they contract forcing the blood into the ventricles. Next, ventricles contract, forcing the blood into the arteries. The contraction of the auricles and ventricles is counted as one beat of the heart. Immediately after the contraction of the ventricles the muscular walls of the auricles relax, allowing the blood in the veins to refill the upper chambers. If you look at the diagram on page 194, you will notice that the muscular walls of the auricles are thinner than the walls of the ventricles. This is because the auricles have merely to force the blood into the ventricles, whereas the ventricles have to force the blood down the arteries and through the capillaries as well.

Now let us follow the path taken by the blood stream in its journey round the body. To do this it will be convenient to begin at a certain point, such as the right auricle, and trace the course of the blood till it returns to the right auricle again.

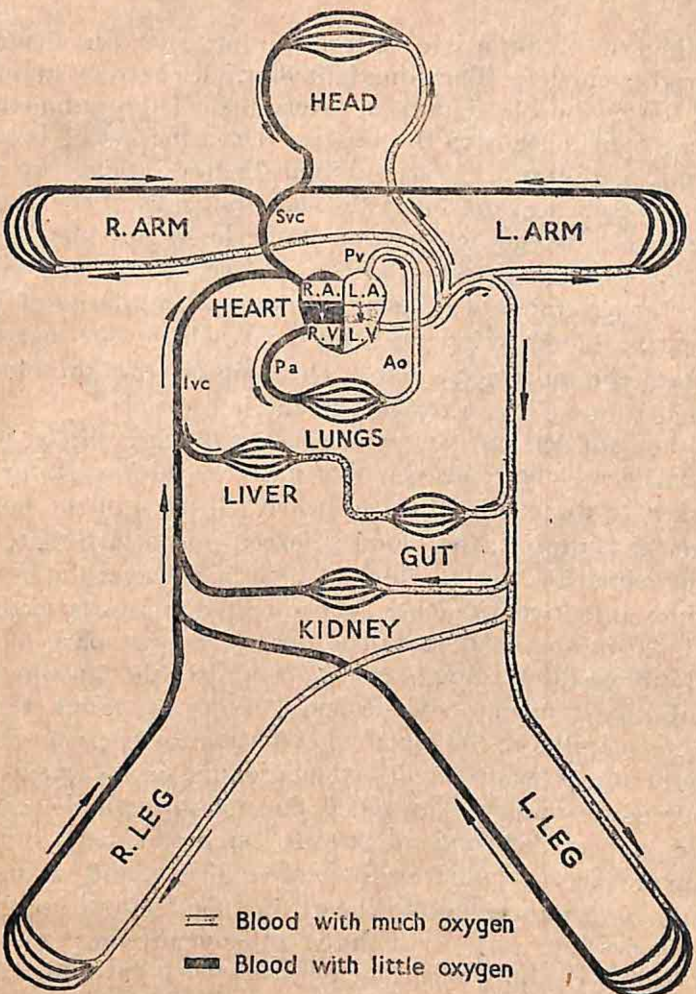
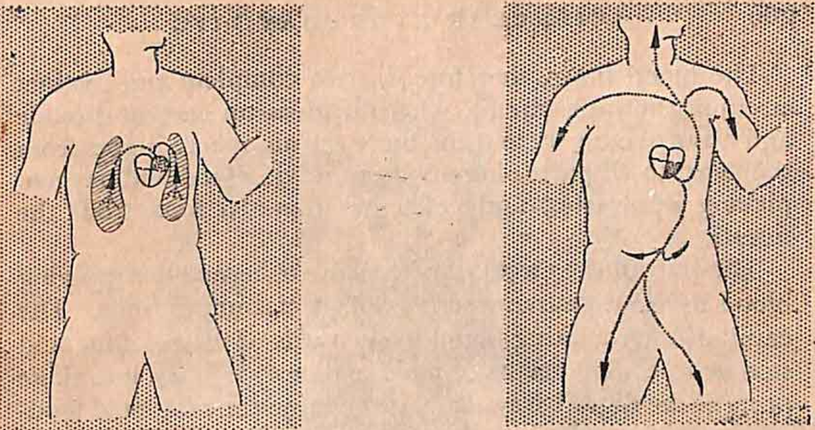


Diagram illustrating blood circulation.
Arrows point in the direction of blood flow.
R.A., right auricle; L.A., left auricle; R.V., right ventricle; L.V., left ventricle; p.a., pulmonary artery; p.v., pulmonary vein; Ao., aorta; S.v.c., superior vena cava; I.v.c., inferior vena cava.

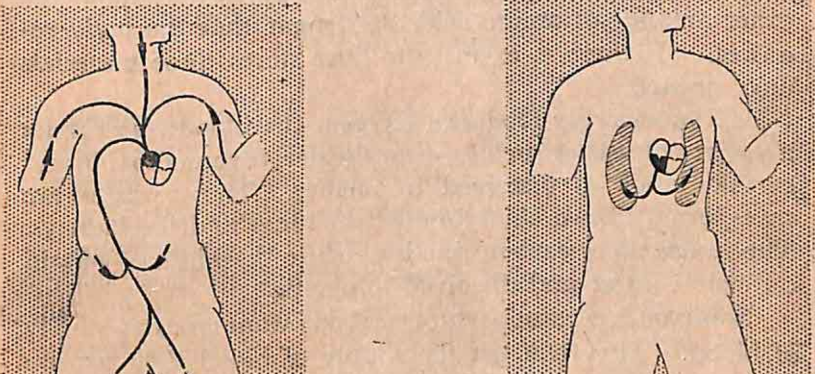
When the right auricle contracts, it forces its contents into the right ventricle. Then the right ventricle contracts in turn, and forces the blood into an artery, called the pulmonary artery, which leads to the lungs. Here the artery breaks up into capillaries. Waste carbon dioxide brought by the blood passes into the lungs through the walls of the capillaries while oxygen passes out of the lungs into the blood flowing through the capillaries. The red blood corpuscles absorb this supply of oxygen. From the capillaries of the lungs the blood passes into tiny veins which join together to form the pulmonary vein. This vein conveys the blood, which is now rich in oxygen, to the left auricle.

When the left auricle contracts, the blood is forced into the left ventricle. This chamber has very thick walls for its work is to direct the blood to nearly all parts of the body. When it contracts, the blood is forced into a large arterial trunk called the aorta, which as soon as it leaves the heart, divides into two branches, one directed upwards leading to the arms and head, and the other to the lower parts of the body. Branches leading from the aorta carry the blood to the capillaries in all parts of the body, except the lungs. While in these capillaries the blood gives oxygen to the parts which need it and picks up much carbon dioxide, excess water and other waste matter. The blood flowing through the capillaries also carries food to the cells: amino-acids for repair, sugar for energy, minerals for body-building, and vitamins. On its return journey to the heart the blood flows from these capillaries into veins. All the veins from the lower part of the body eventually unite together to form a great vein, called the inferior vena cava, while the veins from the upper part of the body likewise join together to form another great vein, called the superior vena cava. Both these veins empty themselves into the right auricle during the period of its relaxation, thus completing the circulation.



1. Blood absorbs oxygen from the lungs and enters the left auricle. It passes to the left ventricle

2. When the left ventricle contracts blood is forced out along the arteries to the body.



3. After passing through capillaries in the tissues and losing oxygen the blood returns to the right auricle.

4. Blood passes into the right ventricle which contracts and forces blood out to the lungs.

—— Blood containing little oxygen (de-oxygenated)

······ Blood containing much oxygen (oxygenated)

What the chambers of the heart can do.

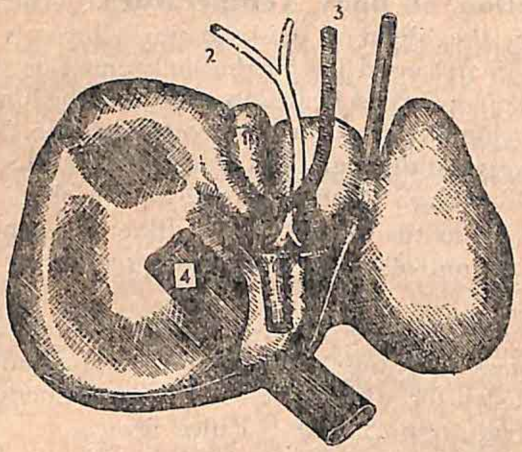
The blood flows, therefore, in two complete and distinct circuits: the lung circuit, where it gives up carbon dioxide and absorbs oxygen, and the body circuit, where it goes from the heart to all parts of the body supplying food and oxygen, picking up wastes, and collecting digested food from the intestines.

The part of the circulatory system concerned in supplying blood to the digestive system is of special importance. The capillaries circulating blood in the walls of the intestine and stomach pass materials for making digestive juices into these parts of the digestive system. At the same time digested foodstuffs pass from the intestines into the capillaries. On leaving the stomach and intestines the capillaries run together to form a vein which takes the blood to the liver. It is the work of the liver to make sure that the blood always contains the exact amount of amino-acids and sugar that the body requires. If there is excess, the liver stores these materials until needed.

Besides carrying food and oxygen, the blood also carries a variety of wastes such as excess water, carbon dioxide and certain kinds of dissolved impurities. These wastes are transported to two chief dumps: the lungs and the kidneys. The lungs expel carbon dioxide, while the kidneys get rid off excess water and dissolved impurities.

Sometimes certain parts of the body want an extra supply of blood. They can get the supply of blood they require without any need for the heart to beat faster than its normal rate. At the conclusion of a meal, for example, there is need for an increase in the flow of blood through the wall of the stomach. As a consequence, arteries leading to the stomach dilate and fill up with blood. Arteries in other parts of the body contract so that the stomach may receive the supply of blood it needs.

On certain occasions, however, the heart beats faster than



The liver and the tubes connected to it.
1. Gall-bladder. 2. Tube leading to small intestine.
3. Artery. 4. Vein.

its normal rate. After vigorous exercise, for example, the muscles concerned require more than their usual supply of oxygen. This means that more blood must flow to them. To bring this about the heart beats at an increased rate.

The oxidation that takes place in our bodies is similar to that of machines in many respects. Nevertheless, there are certain important differences. One of these differences is that our cells do not burn the fuels supplied to them at a temperature high enough to make a flame. The heat produced, however, is sufficient to keep our temperature at 98·4 F. During vigorous exercise we need an extra supply of energy. Consequently, burning takes place more quickly in our bodies, and we feel ourselves becoming warmer. The heat produced in the muscles does not remain there, but is distributed all over the body by the blood. The normal temperature of the body is thus maintained

Regulation of Body Temperature. When the food carried by the blood is oxidised much heat is given off, and what is not used up by the body must be got rid off. A portion of the excess heat is lost through the lungs, but the largest portion is lost at the surface of the skin. The rate at which heat is lost through the skin depends on the rate of the blood-flow through the blood vessels in the skin. This rate of flow varies as the blood vessels dilate or contract, and this itself is controlled by the various regulating centres in the brain.

Fever. The action of microbes or toxins on the heat regulating centres in the brain may result in the regulatory system being adjusted for a higher level of body temperature. Such a rise in body temperature is called fever.

CHAPTER ACTIVITIES

Outdoors

When the blood is forced into the arteries by the contraction of the ventricles, the walls of the arteries bulge out a little to accommodate this extra amount of blood. Consequently there is a regular alteration in the diameter of the arteries which can be felt as far from the heart as the wrist, and is known as the pulse. In fact, it can be felt whenever an artery passes over a bone. Another place to feel the pulse is at the side of the forehead.

Conduct an investigation to determine how much the rate of pulse varies with the age of a person. Find out, as well, how much the rate of our own pulse varies with different kinds of activities. Prepare a report of your investigation which includes a record of the counts and illustrate it in the form of bar graphs.

For your wall newspaper

Copy the drawing on page 197. Use two separate colours to indicate which tubes carry blood rich in oxygen and which tubes carry blood rich in carbon dioxide. Draw a picture of a boy or girl so that it fits over your drawing. Stick the picture over the drawing to make a folding model.

Note-book exercises

1. Imagine yourself a red corpuscle arriving in the right auricle. Write an account of your journey in the circulatory system from the time of your departure from the heart to the time you are brought back by the blood stream to the right auricle.
2. Consult books in your science library and write an account of the life and work of William Harvey.

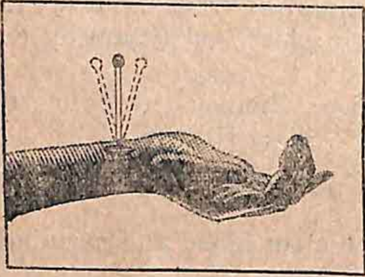
Laboratory work

1. Obtain prepared slides of human blood and examine them under the microscope.
2. There is not a very great difference between the heart of a sheep and that of a human being. Obtain a sheep's heart from the butcher and examine it closely.
3. Catch a live goldfish. Wrap cotton-wool around its gills and keep it continually moist. Secure the fish firmly and spread its tail out on a glass slide. Focus the low-power objective of the microscope on the tail. You will see the blood of the fish in the process of circulating through the capillaries. Release the fish and put it back into the water after about ten minutes.

At home

1. You have read in Book I how minor cuts may be treated by the first aider. Sometimes it happens that the

wound is serious. When you notice the blood coming out in spurts you may be sure that an artery has been cut. In this case pressure should be applied at certain points where the artery lies near the surface. A practical instrument for this purpose is a tourniquet which consists of a flat band at least one inch in width with a pad to lie over the artery and a screw to tighten the band. Join a first aid class and learn how to stop bleeding. There you will learn about the pressure points of the body and the correct use of a tourniquet.



How to magnify your pulse.

2. You can magnify your pulse with the help of a matchstick. Fix a drawing-pin into one end of a matchstick and place the arrangement over your pulse as shown. The matchstick moves back and forth corresponding in its movements to the beat of the heart.

Fill in the blanks

Choose the correct words from this list and use them to fill in the blank spaces: left ventricle, oxygen, intestines, vena cava, red, wastes, to, lung, tubes, veins, white, left auricle, body, auricles, pulmonary vein, from, defend, aorta, valves, connect, corpuscles, two, pulmonary artery, carbon dioxide, capillaries, right auricle, ventricles, plasma, food, four, haemoglobin, blood, right ventricle, heart, disease germs, arteries.

The circulatory system consists of the—and a series of—through which—is pumped. The blood consists of a liquid called—, in which float cells called—. The—corpuscles transport oxygen to all parts of the body with the help of the —they contain. The —corpuscles—the body against attacks from—. The plasma carries—, —and other dissolved substances. The heart consists of—chambers. The two upper chambers are the—and the two lower chambers are the—. —regulate the flow of blood in the heart.—,—and—transport blood around the body. Arteries carry blood—the heart while veins convey blood—the heart. Capillaries—arteries to veins.

Blood flows around the body in—distinct circuits. The —circuit consists of the—which leads from the—to the lungs where it breaks up into capillaries that later unite to form the—which leads to the—. The—circuit consists of the—which leads from the—to the upper and lower parts of the body where it breaks up into capillaries that later unite to form the superior and inferior—which leads to the—. The blood in the lung circuit gives up—to the lungs and absorbs —. The blood in the body circuit supplies all parts of the body with food and oxygen, picks up waste matter and collects digested food from the—.

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